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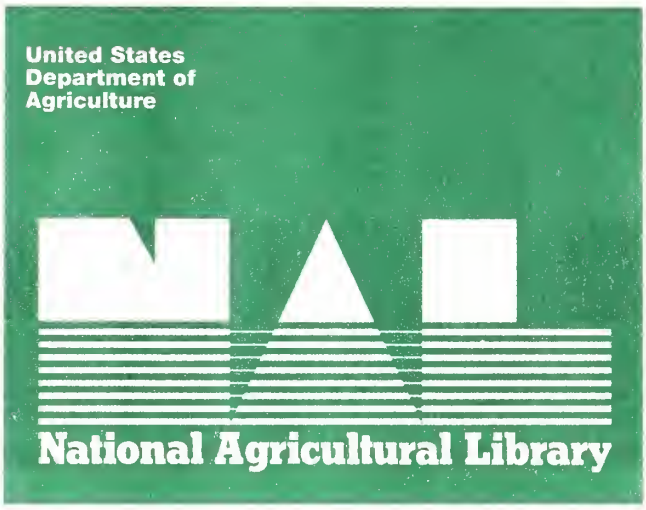
Heliothis/Helicoverpa: 1997 Supplement to the Five-Year National Research Plan for the Development of Suppression Technologies, Including a New Virtual Laboratory Research Plan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Second Review
College Station, Texas
October 7–8, 1997

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November 1998

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Acknowledgments

The National Program Leaders and Steering Committee sincerely appreciate the contributions of all the participants. We especially appreciate the efforts of Jesus Esquivel, Ritchie Eyster, Henry Marshall, Karen Wilcox, Mike O'Neil, and Paul Schleider for their help in local arrangements, accommodations, refreshments, etc.

FOREWORD

This ARS National *Heliothis/Helicoverpa* Working Conference progress report and modified research plan details the second annual review of the revised 1991 (published February 1992)
5-year research action plan and contains a compilation of progress reports, research summaries, a new research and action plan, publications and technology transfer activities. The primary goal of the National *Heliothis/Helicoverpa* research program for development of suppression technologies is to provide the necessary research through a cooperative team and Virtual Laboratory effort that will lead to the development of environmentally-sound, economical, and publicly-acceptable technologies for management of this pest complex.

The first *Heliothis/Helicoverpa* strategic planning conference was held in October 1985 in Memphis, Tennessee. It was devoted to the identification of critical research needs and a review of the ARS research effort by location, as well as an assessment of the number of scientists involved in research on this pest complex. A second ARS-wide working conference with the goal to develop a revised research and action plan was held on September 16-19, 1991, in San Antonio, Texas. The published report of the conference detailed an updated 5-year research and action plan for development of suppression and management technologies for these pests. The research and action plan was categorized into six major research action areas and identified/confirmed high priority research needs: (a) host-plant resistance, (b) chemical control and pesticide application technology, (c) ecology and population dynamics, (d) behavior modifying chemicals, (e) biological control, and (f) genetics, molecular biology, and basic physiology.

A third ARS-Wide Working Conference was held on November 8-11, 1993, in Junction, Texas to review research progress of the 5-year research and action plan since 1991. At this conference, co-coordinators for each of the six research action areas provided progress reports on the research and action plan's lead arrays, as well as research summaries.

The conference reported here represents the fourth ARS-Wide Working Conference to review research progress of the 5-year research and action plan since 1993. As a result of the conference a Virtual Laboratory concept for operating in the future was established. Dr. Dick Hardee has been appointed by the National Program Staff as the *Heliothis/Helicoverpa* National Research Program Coordinator & Virtual Laboratory Director. Six Virtual Project Leaders were also appointed and team members were identified for each of the six high priority virtual projects --
(a) movement and migration, (b) biorational control strategies, (c) ecologically-based management, (d) pathogens, (e) beneficial insects, (f) transgenic crop interactions and host-plant resistance, and (g) efficient use and preservation of insecticides. Each virtual project contains a mission statement, objectives, approach statement, a list of cooperators and a plan for team communication. A new research and action plan for the Virtual Laboratory was developed and is included with this report.

We express our gratitude to all working conference attendees for their contributions to the proceedings and in preparing the comprehensive progress reports and research summaries. We are especially indebted to the conference organizers, action area coordinators and the representatives from the other Federal agencies, universities, commodity groups, and agricultural industries for their interactions and invaluable discussions and recommendations.

James R. Coppedge
Laboratory Director
Southern Crops Research Laboratory

Dick D. Hardee
Heliothis/Helicoverpa National Research Program
Coordinator & Virtual Laboratory Director

Robert M. Faust
National Program Leader
Field and Horticultural Crop Entomology

Executive Summary

Over the years the USDA-ARS has strived to maintain a balanced program on the *Heliothis/Helicoverpa* pest complex and on the management of problems caused by these pests through its research, development and technology transfer efforts. As the "in-house" research agency for the USDA, ARS and its cooperators have coordinated and accelerated their research efforts on *Heliothis/Helicoverpa* in the area of host-plant resistance, chemical control and application technology, ecology and population dynamics, behavior-modifying chemicals, biological control, and genetics, molecular biology, and basic physiology. This research was outlined in a Revised National Suppression Action Plan produced as the result of an ARS-Wide Working Conference held in San Antonio, Texas on September 16-19, 1991. Subsequently an annual review on the research progress of the 1991 5-year research and action plan was held on November 8-11, 1993 in Junction, Texas.

A second *Heliothis/Helicoverpa* revised action plan progress review was held on October 7-8, 1997 in College Station, Texas, with participants from ARS, university scientists, and representatives from commodity groups and industry. The objectives of the review were to
(a) examine the current research status, progress and technology transfer since the progress review held at Junction, Texas in 1993, (b) continue to assess how well customer needs are being met, (c) assess the status of the recommendations made at the 1993 review related to research needs, program management, and communications, (d) identify additional opportunities for increasing partnerships both intra- and extramurally, (e) develop a more focused and streamlined research and action plan for the future, and (f) consider the implementation of a virtual laboratory/project concept by which to operate.

Progress reports and significant accomplishments are highlighted for each of the six action areas, which are host plant resistance; chemical control and application technology; ecology and population dynamics; behavior modifying chemicals; biological control; and genetics, molecular biology and basic physiology. Also included in this report is a list of program publications (1993-1997), a description of technology transfer activities for each action area, and a comprehensive review of an areawide *Helicoverpa* and *Heliothis* management program using pathogens.

A new, highly focused five-year research and action plan which will operated under a virtual laboratory concept (virtual projects) was developed and is included with this report and supplement to the original five-year national research plan for the development of suppression technologies related to the *Heliothis/Helicoverpa* pest complex. The new research and action plan addresses seven high priority research needs: (1) movement and migration; (2) biorational control strategies; (3) ecological-based management; (4) pathogens; (5) beneficial insects; (6) transgenic crop interactions and host-plant resistance; and (7) efficient use and preservation of insecticides. Dr. Dick Hardee of ARS, Stoneville, Mississippi was appointed by the ARS National Program Staff to serve as the Virtual Laboratory Director for the program.

Annual Review Objectives

1. Examine the current research status, progress, and technology transfer since the program review held at Junction, Texas in 1993.

2. Continue to assess how well customers needs are being met.

3. Assess the status of the recommendations made at the 1993 review related to research needs, program management, and communications.

4. Identify additional opportunities for increasing partnerships, both intra - and extramurally.

5. Develop a more focused and streamlined research and action plan for the future.

6. Consider the implementation of a virtual laboratory/project concept by which to operate.

Progress Reports

Action Area I. Host Plant Resistance

Coordinators: R. E. Lynch & B. R. Wiseman

INVESTIGATOR'S NAME(S):		N. W. Widstrom, R. E. Lynch and B. R. Wiseman
AFFILIATION & LOCATION:		USDA-ARS-IBPMRL, Tifton, GA 31793
ACTION AREA:	1	Host Plant Resistance
LEAD ARRAY:	1.1	Develop crop cultivars and/or germplasms with high resistance to reduce numbers of and damage from H/H spp.
SAFEGD ARRAY:	1.1.1	Identify and/or develop new sources of resistance that impact on populations of H/H spp.
OPTIM ARRAY:	1.1.2a	Determine the effectiveness of the resistant cultivar and/or germplasm in reducing populations of H/H spp.
OPTIM ARRAY:	1.1.2b	Determine the interactions of plant resistance to H/H spp. with other methods of integrated pest management
SUPPL ARRAY:	1.1.3	Develop plant resistance technology that would impact or alter the course of action of any of the other arrays.
DATES COVERED BY REPORT:		April 1995 - June 1997

PROGRESS REPORT: Cooperative research was conducted with Rogers Seed Co. to transfer resistance to the corn earworm due to maysin in silks to their elite sweet corn inbreds. The high maysin dent inbreds were GE37 and SC102 and sweet corn lines were 60B, 565, 777, and B31857. Sweet corn inbreds 471-U6 and 81-1 also were included to ensure husk tightness. In 1995, the following crosses were made: GE37 X 60B, SC102 X 777, GE37 X 565, SC102 X B31857, 471-U6 X GE37, and SC102 X 81-1. F2 seeds of these crosses were generated in the winter nursery of 1995-96. F2 segregates contained sufficient maysin levels to provide confidence that high maysin plants could be recovered from selfed backcrosses that are currently being tested. This was particularly true for 565 which produced F2 segregates with maysin levels in the 20 percent range on a silk dry weight basis. Ear-rows from 3-4 plants with the highest maysin concentrations were backcrossed to the sweet corn parent within each kernel type for each cross and planted in the 1996-97 winter nursery. F3 seed from the best (SC102 X 81-1) F2 plants were also included in the winter nursery to obtain BCs to the dent parent, assuring recovery of high maysin types. Selfs were made within ear-rows of selected BC1 plants for the other five crosses involving GE37 and SC102 with sweet corn lines.

FY97 & FY98 WORK PLANS: During the next two years, backcrosses to the recurrent elite sweet corn inbreds will be made accompanied by selection for resistance using maysin analyses and/or antibiosis bioassays with the corn earworm. Beginning with the 2nd or 3rd backcross, we will make testcrosses using sweetcorn seed from the selfs of the converted inbreds and test the experimental crosses for field resistance to the corn earworm, silk-maysin content, antibiosis in laboratory bioassays of silks with the corn earworm, eating qualities, and other agronomic traits.

INVESTIGATOR'S NAME(S):		R. E. Lynch and H. T. Stalker
AFFILIATION & LOCATION:		USDA-ARS-IBPMRL, Tifton, GA 31793
ACTION AREA:	1	Host Plant Resistance
LEAD ARRAY:	1.1	Develop crop cultivars and/or germplasms with high resistance to reduce numbers of and damage from H/H spp.
SAFEGD ARRAY:	1.1.1	Identify and/or develop new sources of resistance that impact on populations of H/H spp.
OPTIM ARRAY:	1.1.2a	Determine the effectiveness of the resistant cultivar and/or germplasm in reducing populations of H/H spp.
OPTIM ARRAY:	1.1.2b	Determine the interactions of plant resistance to H/H spp. with other methods of integrated pest management.
SUPPL ARRAY:	1.1.3	Develop plant resistance technology that would impact or alter the course of action of any of the other arrays.
DATES COVERED BY REPORT:		April 1995 - June 1997

PROGRESS REPORT: Fourteen lines from the interspecific cross *Arachis hypogaea* X *A. cardenasii* were evaluated in the field and seven lines in the laboratory for resistance/susceptibility to insects. Laboratory evaluation of interspecific lines against major defoliators of peanut showed variable levels of resistance to the corn earworm, no resistance to the fall armyworm, and moderate resistance to the velvetbean caterpillar as noted by a reduced host suitability index in line IC 2-5. Damage ratings to plants in the field indicated no resistance in the interspecific lines to the tobacco thrips. However, a high level of resistance to the Southern corn rootworm was observed in most of the lines. Resistance to the potato leafhopper was indicated by reduced damage ratings for all interspecific lines relative to damage on cv. Florunner. Resistance ratings for the potato leafhopper were highest in lines IC 1-16 and IC 1-19 and was evident even under severe potato leafhopper pressure. The levels of resistance to the Southern corn rootworm and potato leafhopper should prove useful in a breeding program to introgress resistance to these insects into elite cultivars.

FY97 & FY98 WORK PLANS: Continue to evaluate the wild species of peanut for resistance to the corn earworm and other insects.

INVESTIGATOR'S NAME(S):		B. R. Wiseman, N. W. Widstrom, M. E. Snook, J. E. Carpenter and R. E. Lynch
AFFILIATION & LOCATION:		USDA-ARS-IBPMRL, Tifton, GA 31793
ACTION AREA:	1	Host Plant Resistance
LEAD ARRAY:	1.1	Develop crop cultivars and/or germplasms with high resistance to reduce numbers of and damage from H/H spp.
SAFEGD ARRAY:	1.1.1	Identify and/or develop new sources of resistance that impact on populations of H/H spp.
OPTIM ARRAY:	1.1.2a	Determine the effectiveness of the resistant cultivar and/or germplasm in reducing populations of H/H spp.
OPTIM ARRAY:	1.1.2b	Determine the interactions of plant resistance to H/H spp. with other methods of integrated pest management.
SUPPL ARRAY:	1.1.3	Develop plant resistance technology that would impact or alter the course of action of any of the other arrays.
DATES COVERED BY REPORT:		June 1993 - June 1997

PROGRESS REPORT: Corn earworm injury in field corn ranged from 0.9 percent to 4.6 percent in 1994; from 0.3 percent to 4.0 percent in 1995; and from 0.7 percent to 4.3 percent in 1996. The C0 through C5 populations of ANTB, EPM, SIM, EPDS, and SIDS were evaluated in 1995-96 and results indicated that no selection progress for earworm resistance had been made. A highly significant negative relationship was found between weight of corn earworm larvae and maysin concentration from fresh silks, and maysin and isomaysin content of oven dried silks. The correlation between larval weight and total flavones from oven dried silks was enhanced (-0.667 for maysin alone to -0.979 for total flavones) compared with that between larval weight and maysin alone. Flavone content decreases as age of silk increases. Ten-day-old silk had no adverse effect on growth of corn earworm larvae. Silk from first ears had higher maysin content and produced lower weight of larvae than silk from second ears on corn plants. Weight of corn earworm neonate and fifth instar fed silk diets of GE37 and SC102 were determined. High levels of antibiosis were expressed in the silks of both inbreds. Very high levels of antibiosis were expressed in the silks from the cross and the reciprocal cross. The growth inhibition factor in resistant silks with maysin as its base, is not due to a deterrent but to an antinutritive factor that binds the protein or results in the degradation of essential amino acids, causing larvae of the corn earworm to excrete large amounts of protein. Corn earworm larvae reared on resistant silk diets did not adversely affect the parasites *Archytus mamaratus* or *Ichneumon promissorius*. Commercially developed transgenic *Bt* field corn from two commercial companies with CryIA(c) and CryIA(b) as well as sweet corn developed by one commercial company with CryIA(b) were evaluated for their effect on corn earworm larvae. It appears sweet corn has a much higher level of resistance against corn earworm larvae than field corn. Also, it appears that CryIA(b) is stronger than CryIA(c) against corn earworm larvae.

FY97 & FY98 WORK PLANS: Continue to study the effects of the resistant plant on corn earworm. Continue to determine the effects of transgenic *Bt* corn plants on corn earworm growth and development and on population reduction.

INVESTIGATOR'S NAME(S):		R. E. Lynch and B. R. Wiseman
AFFILIATION & LOCATION:		USDA-ARS-IBPMRL, Tifton, GA 31793
ACTION AREA:	1	Host Plant Resistance
LEAD ARRAY:	1.1	Develop crop cultivars and/or germplasms with high resistance to reduce numbers of and damage from H/H spp.
SAFEGD ARRAY:	1.1.1	Identify and/or develop new sources of resistance that impact on populations of H/H spp.
OPTIM ARRAY:	1.1.2a	Determine the effectiveness of the resistant cultivar and/or germplasm in reducing populations of H/H spp.
OPTIM ARRAY:	1.1.2b	Determine the interactions of plant resistance to H/H spp. with other methods of integrated pest management.
SUPPL ARRAY:	1.1.3	Develop plant resistance technology that would impact or alter the course of action of any of the other arrays.
DATES COVERED BY REPORT:		May 1996 - June 1997

PROGRESS REPORT: Eight transgenic sweet corn hybrids containing a CryIA(b) gene and provided by Rogers Seed Co. were evaluated for resistance to corn earworm and fall armyworm. All were highly resistant to all ages of corn earworms when they were fed fresh whorl tissue, fresh whorl tissue incorporated into the meridic diet, oven-dried whorl tissue incorporated in the insect diet, regrowth whorl tissue, fresh silks, fresh silks in the diet, oven-dried silks in the diet, or developing kernels incorporated in the diet. Likewise, damage ratings on leaf tissue, on silks, and on ears in the field were significantly lower on the *Bt* corn lines than on the non-*Bt* lines or the susceptible controls. The *Bt* corn lines also showed substantial resistance to the fall armyworm, especially in the field. Resistance to the fall armyworm also was noted in laboratory tests with fresh whorl tissue, fresh whorl tissue incorporated into the meridic diet, oven-dried whorl tissue incorporated in the insect diet, regrowth whorl tissue, fresh silks, fresh silks incorporated in the diet, or oven-dried silks incorporated in the diet. The resistance to fall armyworm, however, was expressed primarily as a slower rate of development as reflected by slower weight gains.

FY97 & FY98 WORK PLANS: Studies are underway to evaluate the effectiveness of the resistance of sweet corn containing the CryIA(b) to the corn earworm and fall armyworm. The research was designed to determine the minimum number of applications of insecticide (0, 1, 3, or 5) that will be necessary to produce injury-free ears using the *Bt* sweet corn. Sweet corn lines GH-0937 (*Bt*+), Bonus (*Bt*-) and Silver Queen will be evaluated with five planting dates.

INVESTIGATOR'S NAME(S):		B. R. Wiseman, K. Bondari, P. F. Byrne and M. E. Snook
AFFILIATION & LOCATION:		USDA-ARS-IBPMRL, Tifton, GA 31793
ACTION AREA:	1	Host Plant Resistance
LEAD ARRAY:	1.2	Determine the biological, biochemical, and/or biophysical mechanisms of resistance to H/H spp.
SUPPL ARRAY:	1.2.3	Determine the genetic basis of the resistant plant materials and/or identified chemical(s) factors.
DATES COVERED BY REPORT:		June 1993 - June 1997.

PROGRESS REPORT: Silks from individual maize plants of resistant and susceptible lines and progeny for six generations consisting of parents, F1, F2, and backcrosses from each of four crosses were used to determine the genetic basis of antibiotic resistance to corn earworm. In the cross of Zapalote Chico X PI340856, genes controlling resistance are dominant in PI340856 to those in Z. Chico. The cross of Z. Chico X GT114 involves parents differing in degree of resistance, and possibly differing for the genetic mechanism by which the resistance is inherited. The resistance of Z. Chico X CI64, an intermediate inbred, is influenced by additive gene effects. The digenic model adequately predicts all generation means of the cross of GT3 X PI340856 except for the F1. The study of the genetics of five additional crosses were completed in 1993-94 using the individual silk mass bioassays from crosses of GE72 X GT114, GE72 X CI83A, GT119 X Ab608A, T218 X N101, and T218 X L621; however, statistical analyses are not complete. Quantitative trait loci and the metabolic pathway of maysin have been studied. Single factor analysis of variance of the silk maysin concentration, corn earworm larval weights and restriction fragment length polymorphism genotypes at flavonoid pathway loci or linked markers for 285 F2 plants indicated that the p1 region on chromosome 1 accounted for 58 percent of the phenotypic variance and showed additive gene action. Twelve genetic stocks from Missouri that control the various pathways of maysin production were evaluated for low earworm weight and the stocks with the alleles a2 and c1-p produced worms with the lowest weights. New C-4"-hydroxy derivatives of maysin and 3'-methoxymaysin were isolated from maize silks. Synthetic 4"-OH-maysin was almost as active as maysin against corn earworm larvae. Maysin and maysin analogues have been determined in over 600 inbreds, populations, plant introductions, and various unassigned collections. Maysin levels ranged from 0 percent to 0.9 percent fresh weight.

FY97 & FY98 WORK PLANS: New corn lines and current breeding materials will be screened for new antibiosis factors and/or higher levels of resistance to corn earworm. Studies of the metabolic pathway of the flavonoids as they affect weight of corn earworm larvae will be continued.

Research Summary

Action Area I. Host Plant Resistance

Compiled by: R. E. Lynch & B. R. Wiseman

1.1: Research under the CRADA with Rogers Seed Co. to transfer resistance to the corn earworm due to high concentrations of maysin in silks to their elite sweet corn inbreds is in the third year. In the preliminary crosses, selections have been made based on maysin analysis of silks from individual plants. F2 segregates contained sufficient maysin levels, particularly among segregates containing sweet corn line 565, to anticipate that high maysin plants could be recovered from selfed backcrosses currently being evaluated. Individual plants from selections containing the highest maysin concentration were backcrossed to the sweet corn parent. Beginning in 1998, selections will be based on both maysin analyses and antibiosis bioassays with the corn earworm. Beginning with the second and third backcross, test crosses, will be made to evaluate for field resistance to the corn earworm.

1.2: Laboratory and field evaluation of interspecific crosses between *Arachis hypogaea x A. cardensaii* showed variable resistance to the corn earworm, no resistance to the fall armyworm, moderate resistance to the velvetbean catepillar, no resistance to the tobacco thrips, high resistance to the corn rootworm, and moderate to high resistance to the potato leafhopper. The levels of resistance to Southern corn rootworm and potato leafhopper should prove useful in a breeding program to introgress resistance to these insects into elite cultivars. Selected lines from these crosses will be released.

1.3: Considerable progress has been made in the area of plant resistance to *Helicoverpa zea.* Significant methodology has been established for ARS work. In addition, many of the methodologies have been transferred to industry. Corn earworm injury in field corn ranged from 0.9 percent to 4.6 percent in 1994; from 0.3 percent to 4.0 percent in 1995; and from 0.7 percent to 4.3 percent in 1996. The C0 through C5 populations of ANTB, EPM, SIM, EPDA, and SIDS were evaluated in 1995-96 and results indicated that no selection progress for earworm resistance had been made. A highly significant negative relationship was found between weight of corn earworm larvae and maysin concentration from fresh silks, and maysin and iomaysin content of oven dried silks. The correlation between larval weight and total flavones from oven dried silks was enhanced (-0.667 for maysin alone to -0.979 for total flavones) compared with that between larval weight and maysin alone. Flavone content decreases as age of silk increases. Ten-day-old silk had no adverse effect on growth of corn earworm larvae. Silk from first ears had higher maysin content and produced lower weight of larvae than silk from second ears on corn plants. Weight of corn earworm neonate and fifth instar fed silk diets of GE37 and SC102 were determined. High levels of antiobiosis were expressed in the silks of both inbreds. Very high levels of antiobiosis were expressed in the silks from the cross and the reciprocal cross. The growth inhibition factor in resistant silks with maysin as its base is not due to a deterrent but to an antinutritive factor that binds the protein or results in the degradation of essential amino acids, causing larvae of the corn earworm to excrete large amounts of protein. Corn earworm larvae reared on resistant silk diets did not adversely affect the parasites *Archytus mamaratus* or *Ichneuman promissorius*. Commercially developed transgenic *Bt* field corn from two commercial companies with CryIA(c) and CryIA(b) as well as sweet corn developed by one commercial company with CryIA(b) were evaluated for their effect on corn earworm larvae. It appears sweet corn has a much higher level of resistance against corn earworm larvae than field corn. Also, it appears that CryIA(b) is stronger than CryIA(c) against corn earworm larvae.

1.4: Eight transgenic sweet corn hybrids containing a gene from *Bacillus thuringiensis* subsp. *Kurstaki (Bt)* for CryIA(b) protein production were evaluated for resistance to the corn earworm, *Helicoverpa zea* (Boddie) and fall armyworm, *Spodoptera frugiperda* (J.E. Smith). Two of the hybrids, *Bt* 95-0901 and *Bt* 95-0902, were homozygous for the *Bt* gene, while the remaining *Bt* hybrids were heterozygous for the gene. Non-*Bt* isogenic hybrids and resistant and susceptible controls also were evaluated. All tests were designed in a randomized complete block with six to eight replications. Laboratory tests revealed that all *Bt* sweet corn hybrids were highly resistant to leaf and silk feeding by neonate, three-day-old and six-day-old corn earworm. Likewise, ear damage due to corn earworm feeding in the field was negligible. With the exception of *Bt* 95-0901, all *Bt* sweet corn hybrids also were moderately resistant to leaf and silk feeding by the fall armyworm. The resistance to fall armyworm was expressed as significantly lower survival of neonates and significantly slower weight gain for all ages of larvae when fed excised whorl leaves of the *Bt* plants. No differences were noted in survival of fall armyworm fed unpolinated silks, but all ages of fall armyworm larvae showed a significantly slower rate of weight gain when fed *Bt* corn silks. *Bt* sweet corn hybrids appear ideal candidates for development of IPM programs for both the fresh and processing sweet corn markets that will drastically reduce the quantity of

pesticides currently used to control pest insects. Furthermore, due to the phenology of sweet corn harvest and the level of expression of the CryIA(b) protein in Novartis *Bt* sweet corn, it is highly unlikely that *Bt* sweet corn will contribute to the development of resistance in insects to *Bt* proteins.

Lead Array 1.5: Methodologies for conducting genetic studies have been developed and used to determine the genetics of silk-resistance to the corn earworm in several inbreds, their cross, and backcrosses. Silks from individual maize plants of resistance and susceptible lines and progeny for six generations consisting of parents, F1, F2, and backcrosses from each of four crosses were used to determine the genetic basis of antibiotic resistance to corn earworm. In the cross of Zapalote Chico X PI340856, genes controlling resistance are dominant in PI340856 to those in Z. Chico. The cross of Z. Chico X GT114 involves parents differing in degree of resistance, and possibly differing for the genetic mechanism by which the resistance is inherited. The resistance of Z. Chico X C164, an intermediate inbred, is influenced by additive gene effects. The digenic model adequately predicts all generation means of the cross of GT3 X PI340856 except for the F1. The study of the genetics of five additional crosses was completed in 1993-94 using the individual silk mass bioassays from crosses of GE72 X GT114, GE72 X C183A, GT119 X AB608A, T218 X N101, and T218 X L621; however, statistical analyses are not complete. Quantitative trait loci and the metabolic pathway of maysin have been studies. Single factor analysis of variance of the silk maysin concentration, corn earworm larval weights and restriction fragment length polymorphism genotypes at flavonoid pathway loci or linked markers for 285 F2 plants indicated that the P1 region on chromosome 1 accounted for 58 percent of the phenotypic variance and showed additive gene action. Twelve genetic stocks from Missouri that control the various pathways of maysin production were evaluated for low earworm weight and the stocks with the alleles z2 and c1-p produced worms with the lowest weights. New C-4"-hydrosy derivatives of maysin and 3'-methoxymaysin were isolated with maize silks. Synthetic 4"-OH0maysin was almost as active as maysin against corn earworm larvae. Maysin and maysin analogues have been determined in over 600 inbreds, populations, plant introductions, and various unassigned collections. Maysin levels ranged from 0 percent and 0.9 percent fresh weight.

Progress Report

Action Area II. Chemical Control

Coordinators: I. W. Kirk & G. W. Elzen

INVESTIGATOR'S NAME(S):		D. D. Hardee
AFFILIATION & LOCATION:		USDA-ARS, SIMRU, Stoneville, MS 38776
ACTION AREA :	2	Chemical Control & Application Technology
LEAD ARRAY:	2.1	Identify effective commercially available chemical insecticides and biorationals (including biological, IGRs, feeding stimulants and attractants) and determine optimal management strategies for H/H on important agronomic crops (corn, cotton, peanuts, soybean, etc.)
SAFEGD ARRAY:	2.1.1	Identify new insecticides/biorationals and/or application techniques for optimization of Lead Arrays 2.1 and 2.2
SUPPL ARRAY:	2.1.3b	Conduct studies to develop a theory of inheritance of insecticide resistance and to determine insecticide resistance mechanisms
SUPPL ARRAY:	2.1.3c	Conduct studies to develop insecticide resistance management strategies for H/H
DATES COVERED BY REPORT:		July 1993 – September 1997

PROGRESS REPORT: Monitoring for resistance in *Helicoverpa zea* and *Heliothis virescens* to *Bt* insecticide and proteins in *Bt* cotton was initiated in FY96 to establish baseline susceptibility levels for continual resistance monitoring across the Cotton Belt. Twenty-three colonies (mostly *H. zea*) from four states were subjected to MVP II in spray chamber bioassays. Monitoring results showed no shifts in baseline susceptibility levels of biological insecticides (and thus, *Bt* cotton), but data are very preliminary, especially in TBW because of low numbers in the 1996 season.

FY 97 & FY 98 WORK PLANS: Colonies of both species will be obtained from as many sites as possible, and colonies from both *Bt* and non-*Bt* corn and cotton will be subjected to MVP II spray chamber bioassays, as well as to laboratory diet containing actual *Bt* proteins from MVP II, *Bt* corn, and *Bt* cotton.

INVESTIGATOR'S NAME(S):		G. W. Elzen
AFFILIATION & LOCATION:		USDA-ARS, BIRU, Weslaco, TX
ACTION AREA:	2	Chemical Control & Application Technology
LEAD ARRAY:	2.1	Identify effective commercially available chemical insecticides and biorationals (including biological, IGRs, feeding stimulants and attractants) and determine optimal management strategies for H/H on important agronomic crops (corn, cotton, peanuts, soybean, etc.)
SUPPL ARRAY:	2.1.3b	Conduct studies to develop a theory of inheritance of insecticide resistance and to determine insecticide resistance mechanisms
SUPPL ARRAY:	2.1.3c	Conduct studies to develop insecticide resistance management strategies for H/H
DATES COVERED BY REPORT:		July 1993 – September 1997

PROGRESS REPORT: Determined tobacco budworm resistance levels in the Mississippi Delta; examined synergism. Participated in research to establish a method for monitoring resistance in tobacco budworm to nonpyrethroid insecticides. Resistance levels remained highest to pyrethroids, followed by carbamates and a cyclodiene, followed by organophosphates. Examined the issue of cross-resistance in tobacco budworm and determined that cross-resistance was not present between OPs and carbamates. Studied inheritance and reversion of insecticide resistance in tobacco budworm. Co-dominant mechanisms of resistance to the pyrethroid and carbamate insecticides were suggested from the data. Resistance to a pyrethroid and a carbamate did not revert to susceptibility until 12 generations in culture. Continued to determine resistance levels in tobacco budworms and participated in a study of the toxicological responses of tobacco budworm from Louisiana, Mississippi, and Texas. Participated in a four year study of resistance to OPs, carbamates, and cyclodienes in tobacco budworm. Examined changes in insecticide tolerance in tobacco budworm adults, larvae, and eggs; found that imadicloprid, a new class of insecticide designed primarily for control of sucking insects, had ovicidal and larvicidal activity on tobacco budworm. Tolerance to imidacloprid was present in a field population resistant to carbamates but not to OPs, suggesting the possibility of cross-resistance between carbamates and imidacloprid. Resistance to carbamates was clearly present in some populations susceptible to profenofos, indicating the presence of different mechanisms of resistance for the two classes of insecticides. Significant resistance to *Bacillus thuringiensis* Berliner was observed in one strain of tobacco budworm.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		J. D. Lopez, Jr.
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	2	Chemical Control and Application Technology
LEAD ARRAY:	2.1	Identify effective commercially-available chemical insecticides and biorationals (including biologicals, IGRs, feeding stimulants and attractants) and determine optimal management strategies for H/H on important agronomic crops (corn, cotton, peanuts, soybean, etc.)
SAFEGD ARRAY:	2.1.1	Identify new insecticides/biorationals and/or application techniques for optimization of Lead Arrays 2.1 and 2.2
OPTIM ARRAY:	2.1.2a	Develop improved formulations of candidate insecticides/biorationals
DATES COVERED BY REPORT:		July 1993 – September 1997

PROGRESS REPORT: A major effort was undertaken to evaluate the feeding response and toxicity of numerous commercially-available insecticides to adult corn earworms when these were mixed with various feeding stimulants. Feeding response was determined by the effects on proboscis extension and gustation of insecticide concentrations from 1 to 10,000 ppm of active ingredient in the feeding stimulant solution (wt:vol). Toxicity was based on lethal concentration determinations as well as the lethal time for various multiples of the LC^{90} or LC^{99}. Several insecticides were identified that were compatible with feeding stimulants in that they had little or no effect on inhibition of feeding. Among some of these insecticides were carbaryl, methomyl, acephate, boric acid, and endosulfan. Several insecticides were also identified that were extremely toxic to the adults with LC90 values of less than 10 ppm AI; however, the most toxic insecticides were not all the ones that did not or minimally inhibited adult feeding. The most toxic insecticides also caused mortality within one hour at concentrations 10 to 100 times the LC^{90} or LC^{99}. Formulation was found to influence the feeding response and toxicity of some insecticides to adult corn earworms when ingested. Soluble and flowable formulations were the most compatible for feeding. Two relatively new insecticides, spinosad and emamectin benzoate were found to be highly toxic and compatible when ingested by adult corn earworms; however, mortality occurred slower than with other insecticides. Field evaluations in corn and cotton of some of the more toxic insecticides indicated that some of the commercially-available insecticides can kill adult corn earworms at concentrations considerably lower than those recommended for larval control, but some highly toxic insecticides were found to repel the adults. For some insecticides available in different formulations, EC formulations tended to be more toxic than WP formulations. These studies show that there are commercially-available insecticides that are suitable for use in the development of adult control technology using feeding attractants and stimulants. Studies were initiated to evaluate some commercially-available IGRs for effects on feeding response, mortality, and reproduction of adult corn earworms. IGRs evaluated were Torus (fenoxycarb), Confirm (tebufenozide), Knack (pyriproxyfen), and Larvidex (cyromazine) at concentrations up to 10,000 ppm AI (wt:vol) in a feeding stimulant solution. None of the IGRs evaluated significantly reduced larval hatch or depressed growth and development of immature stages that hatched from eggs oviposited by treated females. Also, none of them were toxic to adults. Amitraz, a contact poison for heliothine eggs, was also evaluated. Gustation of amitraz did not interfere with oviposition or larval hatch. Amitraz was toxic to adults at higher concentrations.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		J. E. Mulrooney
AFFILIATION & LOCATION:		USDA-ARS, APTRU, Stoneville, MS 38776
ACTION AREA:	2	Chemical Control and Application Technology
LEAD ARRAY:	2.2	Determine and compare optimal insecticide application techniques utilizing best available technology (aerial, ground-rig, chemigation, etc.) to improve application methods for improved efficacy and lower environmental impact of currently used chemical insecticides and biorationals.
OPTIM ARRAY:	2.2.2	Develop improved insecticide application methodology for creation of optimal droplet sizes, reduction in drift, and increased probability of deposition onto the target
SUPPL ARRAY:	2.2.3	Elucidate mechanisms of insecticide transfer from plant surface to insect (persistence of insecticide on plant)
DATES COVERED BY REPORT:		June 1993 – May 1997

PROGRESS REPORT: In rainfastness tests of eleven adjuvants, Bond and Plyac were the only adjuvants to significantly decrease the amount of bifenthrin washed off the surface of cotton leaves. Agridex, soydex, and Dyne-Amic significantly increased wash-off of bifenthrin. Bioassays of bifenthrin + Bond and Dipel + Bond mixtures using tobacco budworm and soybean loopers respectively, showed that Bond did not interfere with the uptake of bifenthrin, nor did it have antifeedant or repellent effects on soybean looper. In feeding tests in which adjuvants were incorporated into artificial diet, Dyne-Amic and Kinetic significantly reduced the weight of tobacco budworm larvae. However, these adjuvants did not enhance the efficacy of Dipel 2X against tobacco budworm larvae. Ultra low volume aerial and ground tests of Carrier 038, an ultra violet light protectant, showed no significant increases in tobacco budworm mortality from microbial insecticides (Gemstar, Biocot XLP, Biocot XL, and Dipel ES) applied with Carrier 038. Spray drift tests comparing different air-assisted ground sprayers showed that off-target drift differs between sprayers. In general, off-target drift increased when carrier volumes were decreased; however, with one sprayer, spray drift decreased as carrier volume was reduced. Operating air-assisted sprayers at full air velocity over early season cotton canopies increased spray drift. Aerial application tests showed that increasing droplet size resulted in increased cotton canopy penetration. Similar deposition tests showed no significant increase in canopy penetration of sprays that were applied using Chimavir winglets mounted on the spray boom of the aircraft. Results of an aerial spray drift test of nine different retardants showed that HM9621, Sanag 41F and 38F, Drop Zone, and Sta-Put were most effective in reducing drift. No reduction in the efficacy of malathion against boll weevils was observed when these drift retardants were included in the spray mixture.

FY 97 & FY98 WORK PLANS:

Research Summary

Action Area II. Chemical Control and Application Technology

Compiled by: I. W. Kirk

Lead Array 2.1: Identify effective commercially available chemical insecticides and biorationals (including biologicals, IGRs feeding stimulants, and attractants) and determine optimal management strategies for H/H on important agronomic crops (corn, cotton, peanuts, soybeans). Imadicloprid was demonstrated to have ovicidal and larvicidal activity on *Heliothis virescens.* Resistance monitoring of *Helicoverpa zea* and *Heliothis virescens* to *Bt* insecticides and cottons was initiated. Resistance levels were highest for pyrethroids, and followed by carbamates, cyclodienes, and organophophates. Preliminary results show no shift in baseline susceptibility levels. Other resistance studies with *H. virescens* showed no cross-resistance between OPS and carbamates. Cross-resistance to pyrethroids and carbamates did not revert to susceptibility until 12 generations. Resistance studies further showed the presence of different mechanisms of resistance for two classes of insecticides and one significant resistance to *Bt.* A major effort was undertaken to evaluate the feeding response and toxicity of numerous commercially-available insecticides to adult corn earworms when these were mixed with various feeding stimulants. Feeding response was determined by the effects on proboscis extension and gustation of insecticide concentrations from 1 to 10,000 ppm of active ingredient in the feeding stimulant solution (wt:vol). Toxicity was based on lethal concentration determinations as well as the lethal time for various multiples of the LC^{90} or LC^{99}. Several insecticides were identified that were compatible with feeding stimulants in that they had little or no effect on inhibition of feeding. Among some of these insecticides were carbaryl, methomyl, acephate, boric acid, and endosulfan. Several insecticides were also identified that were extremely toxic to the adults with LC90 values of less than 10 ppm AI; however, the most toxic insecticides were not all the ones that did not or minimally inhibited adult feeding. The most toxic insecticides also caused mortality within one hour at concentrations 10 to 100 times the LC^{90} or LC^{99}. Formulation was found to influence the feeding response and toxicity of some insecticides to adult corn earworms when ingested. Soluble and flowable formulations were the most compatible for feeding. Two relatively new insecticides, spinosad and emamectin benzoate were found to be highly toxic and compatible when ingested by adult corn earworms; however, mortality occurred slower than with other insecticides. Field evaluations in corn and cotton of some of the more toxic insecticides indicated that some of the commercially-available insecticides can kill adult corn earworms at concentrations considerably lower than those recommended for larval control, but some highly toxic insecticides were found to repel the adults. For some insecticides available in different formulations, EC formulations tended to be more toxic than WP formulations. These studies show that there are commercially-available insecticides that are suitable for use in the development of adult control technology using feeding attractants and stimulants. Studies were initiated to evaluate some commercially-available IGRs for effects on feeding response, mortality, and reproduction of adult corn earworms. IGRs evaluated were Torus (fenoxycarb), Confirm (tebufenozide), Knack (pyriproxyfen), and Larvidex (cyromazine) at concentrations up to 10,000 ppm AI (wt:vol) in a feeding stimulant solution. None of the IGRs evaluated significantly reduced larval hatch or depressed growth and development of immature stages that hatched from eggs oviposited by treated females. Also, none of them were toxic to adults. Amitraz, a contact poison for heliothine eggs, was also evaluated. Gustation of amitraz did not interfere with oviposition or larval hatch. Amitraz was toxic to adults at higher concentrations.Monitoring for *Bt* resistance in cotton initiated. Resistance in insects to *Bacillus thuringiensis (Bt)* delta endotoxin proteins has recently received considerable interest both nationally and internationally for several reasons, but primarily because of the recent registration and deployment of transgenic plants in many countries. Preliminary *Bt* resistance monitoring in cotton in populations of cotton bollworm, *Helicoverpa zea* (Boddie), and tobacco budworm, *Heliothis virescens* (Fabricius) was initiated in 1996 by subjecting 23 different populations of these insects collected in Arkansas, Mississippi, Oklahoma, and Texas to field doses of MVP II biological insecticide in spray chamber bioassays [the toxic protein in MVP II is the closest to toxicological properties of all *Bt* insecticides to the CryIA(c) protein expressed in transgenic cotton]. Monitoring results showed no shifts in baseline susceptibility levels of biological insecticides (and thus *Bt* cotton), but data are very preliminary, especially in tobacco budworm because of low numbers in the 1996 season. Resistance monitoring will expand and continue in 1997. (D. D. Hardee, Stoneville, MS)

Lead Array 2.2: Determine and compare optimal insecticide application techniques utilizing best available technology (aerial, ground-rig, chemigation, etc.) to improve application methods for improved efficacy and lower environmental impact of currently used chemical insecticides and biorationals. Studies with air-assisted ground sprayers generally showed that spray drift increases with decreases in spray rate and increased air velocities. Studies with aerial spray drift retardants show only about half of these materials are effective in reducing spray drift. The drift retardants were not active in reducing efficacy of malathion

against boll weevils. Only about 20 percent of the spray adjuvants studied were active in increasing rainfastness of chemical pesticides. The

active adjuvants did not produce antifeedant and repellent effects on soybean loopers.Efficacy of five different microbial insecticideswas not improved by co-application of the ultraviolet light protectant Carrier 038. Spray adjuvants, Dyne-Amic and Kinetic, did not improve the efficacy of Dipel 2X against tobacco budworm larvae.

Progress Report

Action Area III. Ecology & Population Dynamics

Coordinators: J. D. Lopez & J. K. Westbrook

INVESTIGATOR'S NAME(S):		J. D. Lopez, Jr., T. N. Shaver, and K. R. Beerwinkle
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	3	Ecology and Population Dynamics
LEAD ARRAY:	3.1	Quantify preflight activities
OPTIM ARRAY:	3.1.2a	Determine influence of reproductive and feeding sites available to newly emerged adult population
DATES COVERED BY REPORT:		July 1993 – September 1997

PROGRESS REPORT: Evaluation of feeding attractants and stimulants in senescent corn during the period of adult emergence shows that large numbers of adult corn earworms respond to field-applied materials during early evening, indicating that an as yet unknown proportion of adults emerging in the corn the previous night remain in the corn field and forage for food in the evening following the night of emergence. These results identify the potential for use of feeding attractants/stimulants for adult control of corn earworms in senescent corn prior to migration or dispersal into other crops.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		J. F. Esquivel, D. W. Spurgeon, T. N. Shaver, J. R. Raulston, and P. D. Lingren
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX USDA-ARS, CIRU, Weslaco, TX
ACTION AREA:	3	Ecology and Population Dynamics
LEAD ARRAY:	3.1	Quantify pre-flight activities
OPTIM ARRAY:	3.1.2a	Determine influence of reproductive and feeding sites available to newly-emerged adult population
DATES COVERED BY REPORT:		August 1993 - May 1997

PROGRESS REPORT: Nightly observations were conducted in blooming citrus groves in the Lower Rio Grande Valley (LRGV) of Texas to document adult corn earworm behavior presumably before migration to more northern climates. Blooming citrus coincides with early season corn earworm populations and provides a food source for these insects in the LRGV. During 1994, >64 percent of insects were caught before 0100 hours. Males were actively feeding and flying during early evening hours. Despite such activity, all behavioral categories for males exhibited >90 percent citrus pollen contamination. Sitting behavior was more evident for females yet all insects in this category, including mating, possessed citrus pollen. This suggests early feeding or feeding prior to the night of capture. Mating behavior occurred between 0200 and 0500 hours. However, dissections indicate mated females were observed throughout the night. Presence of mated females (>60 percent) suggests an aged feral population. Number of spermatophores per female ranged from 0-5. During 1995, sitting behavior was predominant for both sexes. Overall citrus pollen contamination was lower than 1994 observations with females exhibiting slightly higher contamination rates. Mating insects were collected at 2300, 0300, and 0400 hours only. Similar to 1994 studies, mated females were collected throughout the night except for 0600 hours. Virgin females comprised <20 percent of captures suggesting an aged population of adult females. Number of spermatophores per female ranged from 0-7. These observations suggest that corn earworm adults utilize citrus blooms as a food source. Females outnumbered males during both observation years. Females have a higher requirement for carrying on physiological processes so capturing more females suggests that females are actively seeking a food source. Further, capture of mating insects suggests citrus groves are also used as reproductive sites.

FY97 & FY98 WORK PLANS: No further field work planned.

INVESTIGATOR'S NAME(S): J. K. Westbrook

AFFILIATION & LOCATION: USDA-ARS, APMRU, College Station, TX

ACTION AREA: 3 Ecology & Population Dynamics

LEAD ARRAY: 3.1 Quantify pre-flight activities

OPTIM ARRAY: 3.1.2b Determine meteorological influences on newly emerged adults

DATES COVERED BY REPORT: Aug. 1993–May 1997

PROGRESS REPORT: No progress reported.

FY97 & FY98 WORK PLANS: None.

INVESTIGATOR'S NAME(S): J. K. Westbrook and T. N. Shaver

AFFILIATION & LOCATION: USDA-ARS, APMRU, College Station, TX

ACTION AREA: 3 Ecology & Population Dynamics

LEAD ARRAY: 3.2 Determine adult response to plants and plant volatiles

DATES COVERED BY REPORT: Aug. 1993–May 1997

PROGRESS REPORT: Vacuum air pumps sampled approximately 0.5 m^3 of air through adsorbent media (tenax and charcoal) and were collected for 10 h nightly periods. Eighty-eight milligrams each of phenylacetaldehyde (PA) and methylsalicylate (MS) were applied in solution to each of three cotton dental rolls. PA and MS were released from cotton rolls at rates of 80 percent and 73 percent, respectively, per 10 h nocturnal period. The maximum concentration of PA adsorbed in a column at the volatile source was 3.1538 mg/m^3 for PA and 0.8749 mg/m^3 for MS. Maximum concentrations of 0.0177 mg/m^3 and 0.0071 mg/m^3 were collected at a radial distance of 5 m from the volatile release location for PA and MS, respectively. Concentrations of PA and MS greater than 0.0001 mg/m^3 were detected at heights of 0.1 m and 1.5 m (top of corn canopy). No PA or MS was detected in vacuum air samples at a radial distance of 10 m from the volatile source. Maximum nocturnal wind speed was at 1.5 H, where H is the canopy height (approx. 1.5 m). Minimum nocturnal wind speed was at 0.5 H. Nocturnal minimum air temperature was located at 1.1 H. Nocturnal relative humidity at mid-canopy (0.5 H) was greater than that above (2 H) the canopy. Progress has advanced to Year 3-4; more efficient air sampling and wind measurement is underway in 1997.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		J. D. Lopez, Jr., T. N. Shaver, and K. R. Beerwinkle
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	3	Ecology and Population Dynamics
LEAD ARRAY:	3.2	Determine adult response to plants and plant volatiles
OPTIM ARRAY:	3.2.2	Determine and define interaction of adults with local plant populations
DATES COVERED BY REPORT:		July 1993 – September 1997

PROGRESS REPORT: Early season observations of adult corn earworm feeding activity indicated that ryegrass, *Lolium perenne*, infected with ergot, *Claviceps purpurea*, and containing honeydew is an important adult food source. Efforts to characterize the adult response to this food source have not been successful because of environmental conditions which have prevented widespread occurrence and infection of ryegrass in the local area for two successive years. Positive proboscis extension responses of adult corn earworms to numerous locally occurring flowering plants (herbs, trees, and grasses) have shown that many of these plants provide suitable stimuli for feeding and may serve as adult food plants. Very few flowering plants did not induce proboscis extension. Proboscis extension response to male and female flowers of willow indicated that the degree of positive response was related to the age of the flowers with the greatest response corresponding to the period when floral nectaries were functional. Proboscis extension response to both post oak and sweet corn tassels was influenced by the presence of aphids/honeydew. Intensive field evaluations with a feeding attractant identified from *Gaura* have shown that both corn earworm/bollworm and tobacco budworm respond to the feeding attractant and feed on a feeding stimulant applied in the same area on corn and cotton.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		K. R. Beerwinkle, T. N. Shaver, and J. D. Lopez, Jr.
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	3	Ecology and Population Dynamics
LEAD ARRAY:	3.2	Determine adult response to plants and plant volatiles
OPTIM ARRAY:	3.2.2	Determine and define interaction of adults with local plant populations
DATES COVERED BY REPORT:		July 1993–May 1997

PROGRESS REPORT: Numerous laboratory bioassays with olfactometers (Beerwinkle et al. 1996) were conducted to evaluate the attractiveness of various natural and synthetic plant volatiles to adult *Helicoverpa zea*. In these studies, the moths demonstrated positive attractance to the flowering parts of 37 different plant species tested, confirming their polyphagous nature. Chemical analyses of the natural volatiles from several different plants that were observed to be attractive in olfactometer bioassays revealed a wide range of chemical constituents among those tested. Therefore, research was directed toward identifying the active attractant chemicals in *Gaura drummondii*, a plant that had been observed in both field and laboratory studies to be highly attractive to feeding *H. zea*. Through a series of olfactometer bioassays, five major moth-attractant chemicals were isolated from among the 14 compounds originally identified in *G. drummondii* flower volatiles. A synthetic attractant containing the five identified chemicals is presently being further field tested under a CRADA established with a major agricultural chemical corporation and is the subject of a current U. S. patent application.

FY97 & FY98 WORK PLANS: Research will continue with cooperators to perfect the synthetic plant attractant for adult *H. zea*.

INVESTIGATOR'S NAME(S): J. K. Westbrook, W. W. Wolf, P. D. Lingren, and J. R. Raulston

AFFILIATION & LOCATION: USDA-ARS, APMRU, College Station, TX

ACTION AREA: 3 Ecology & Population Dynamics

LEAD ARRAY: 3.3 Determine migratory and trivial flight initiation and termination

SUPPL ARRAY: 3.3.3 Identify meteorological events that affect flight initiation and orientation

DATES COVERED BY REPORT: Aug. 1993–May 1997

PROGRESS REPORT: Scanning radar measurements in the Lower Rio Grande Valley (LRGV) indicated that corn earworm-size targets were flying at a mean airspeed of 5 m/s and headed 13 degrees clockwise with respect to the wind displacement. Insect flight initiated at 0.5 h after sunset and peaked at 1.25 h after sunset. Collective alignment of corn earworm-size radar targets in the LRGV in May and June occurred each night (N=84) during a six-year period. The angular difference between the collective insect alignment and the wind displacement direction was 30 degrees or more during 85 percent of those nights when collective alignment occurred for more than 1 h and the collective alignment occurred within an atmospheric layer of at least 200 m depth. Collective alignment was perpendicular to the wind direction when the wind was from the southeastern quadrant (prevailing climatological wind direction). Individual insect flight trajectories on the Texas High Plains in August revealed substantial variability of heading which indicated a significant biological component to their population dispersal. A mean flight speed of 4.5 m/s and mean heading of 25 degrees counterclockwise to the wind displacement direction were noted. Progress has advanced to Year 4.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S): S. D. Pair

AFFILIATION & LOCATION: USDA-ARS, SCARL, Lane, OK

ACTION ARRAY: 3 Ecology and Population Dynamics

LEAD ARRAY: 3.4 Determine origins of adult populations

DATES COVERED BY REPORT: July 1993 – September 1997

PROGRESS REPORT: Determined the parameters governing earworm population dynamics on corn in the LRGV, quantitated potential adult production, and defined the weather related transport mechanisms involved in the movement of populations into northern areas. Characterized the temporal sequence of population development with movement in the LRGV, Uvalde, and Lubbock, TX (Years 2&3).

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME (S):		G. D. Jones
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	3	Ecology and Population Dynamics
LEAD ARRAY:	3.4.1	Determine origins of adult populations
SAFEGD ARRAY:	3.4.1	Develop regional SEM pollen reference libraries
DATES COVERED BY REPORT:		July 1993 – September 1997

PROGRESS REPORT: The Areawide Pest Management Research Unit's (APMRU) Pollen Reference Collection was started in 1994. The APMRU Collection contains pollen material from approximately 1,000 taxa collected in Texas, other states, and Mexico and is made up of entirely entomophilous (insect pollinated) taxa. This collection contains five types of pollen identification material: scanning electron micrographs, light micrographs, permanent glass slides, field and/or herbaria collected polleniferous material, and plant vouchers. On loan to APMRU are three other pollen reference collections: Stanley D. and Gretchen D. Jones Collection, Meredith Hoag Lieux Collection, and David and Susan Jarzen Collection. Stanley D. and Gretchen D. Jones Pollen Collection contains 2,500 taxa from the United States, Belize, Canada, and Mexico. The main emphasis is pollen from Texas plants and the majority are entomophilous. Like the APMRU Collection, the S. & G. Jones Collection contains five types of pollen identification material: scanning electron micrographs, light micrographs, permanent glass slides, field and/or herbaria collected polleniferous material, and plant vouchers. Pollen of the Meredith Hoag Lieux Collection represents types found in the southeastern United States. Approximately 450 taxa of entomophilous and anemophilous (wind pollinated) types are represented by scanning electron and light micrographs, permanent glass slides and pollen vials. David and Susan Jarzen Pollen Collection consists of 1,300 glass slides from plants found in tropical regions of the world. There are approximately 1,300 taxa represented in this collection. There are approximately 7,500 worldwide taxa represented in the four collections. All four collections are housed at APMRU and available for pollen research and identification. *Pollen of the Southeastern United States* (Jones et al. 1995) is an atlas of 399 taxa of pollen from the scanning electron micrographs from the S. & G. Jones and Meredith Hoag Lieux Collections. The taxa in this atlas are important for entomopalynology (study of pollen on or in insects) and melissopalynology (study of pollen in honey). Representative pollen types can be viewed on the pollen page of APMRU's homepage.

Because the identity of reference pollen grain depends on the plant from which the pollen was obtained, that plant itself must be accurately identified and preserved as a voucher specimen. In 1995 APMRU began a collaborative agreement with Botanical Research Center for plant identification and storage of voucher specimens.

FY97 & FY98 WORK PLANS: Accurate pollen identification is the key to proper identification of foraging resources, possible source zones, etc. Because of the importance of a good reference collection for pollen identification, the collection is constantly being upgraded and new taxa added. A companion atlas of *Pollen of the Southeastern United States* is being produced. This new atlas will include light micrographs of the same taxa found in *Pollen of the Southeastern United States*

INVESTIGATOR'S NAME(S): J. K. Westbrook, W. W. Wolf, P. D. Lingren, J. R. Raulston, J. D. Lopez, Jr., J. F. Esquivel, and G. D. Jones

AFFILIATION & LOCATION: USDA-ARS, APMRU, College Station, TX

ACTION AREA: 3 Ecology & Population Dynamics

LEAD ARRAY: 3.4 Determine origins of adult populations

OPTIM ARRAY: 3.4.2a Identify and characterize source population zones

DATES COVERED BY REPORT: Aug. 1993–May 1997

PROGRESS REPORT: Populations of adult corn earworms were monitored in the Lower Rio Grande Valley (LRGV) using entomological radars and pheromone traps. Adult corn earworms marked externally with citrus pollen were captured in February and March as far as 660 km north of the LRGV, the nearest source of commercial citrus production. Entomological radars detected comparable concentrations of airborne insects along the Mexico-Texas border from Edinburg to Del Rio, Texas, which suggested a large source of migrant corn earworms in Mexico in March. Moths fed on a sugar solution mixed with *Lycopodium* spores which had been applied to senescent corn in the LRGV, and were captured in pheromone traps as far as 230 km north during the period of peak corn earworm emergence in June. Capture events throughout Central Texas were well correlated (x^2 =chi 60.56, $p < 0.0001$) with estimated insect flight trajectories from the LRGV and local minimum air temperature. Following a severe winter freeze that devastated citrus production in the LRGV, calculated insect flight trajectories indicated that captured corn earworm moths in Oklahoma in the spring of 1990 which were marked with citrus pollen had traveled from Florida, the Bahamas, Cuba, Yucatán Peninsula, or northern Central America. Progress has advanced to Year 5.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		J. D. Lopez, Jr.
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	3	Ecology and Population Dynamics
LEAD ARRAY:	3.4	Determine origins of adult populations
OPTIM ARRAY:	3.4.2a	Identify and characterize source population zones
OPTIM ARRAY:	3.4.2b	Utilize standardized sampling procedures in multiple cropping systems across geographical regions to determine chronology of developing populations
OPTIM ARRAY:	3.4.2c	Determine regions in Mexico that may influence development of U. S. populations in the spring
SUPPL ARRAY:	3.4.3b	Develop efficient marking techniques for tracing moth population origin
DATES COVERED BY REPORT:		July 1993 – September 1997

PROGRESS REPORT: Sex pheromone traps for corn earworm/bollworm, and tobacco budworm have been operated continuously from early February to early November in an agricultural area in the Brazos River Valley close to College Station, TX. These data are available and, when added to previously-available data from the same area extending back to the late 1970's through the 1980's, provide a data base that will be used to evaluate the effect of various factors such as temperature, wind speed and direction, insecticide use, etc., on the temporal pattern of occurrence of both species. These data will also be used in conjunction with sex pheromone trapping data from other geographical areas to determine interrelationships. Various dyes (FD&C, Day-Glo®, water tracing fluorescent, etc.) have been evaluated for use in conjunction with feeding attractants and stimulants in the laboratory and preliminarily in the field for marking adult moths for dispersal studies. Various dyes which do not interfere with feeding when mixed with a feeding stimulant and which provide a suitable mark for detection have been identified. No progress was made in determining regions in Mexico that may influence development of U. S. populations in the spring.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		J. F. Esquivel, G. D. Jones, J. R. Raulston, D. W. Spurgeon, J. Loera, and J. R. Coppedge
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX USDA-ARS, CIRU, Weslaco, TX SARH, INIFAP, Rio Bravo, Tamps., Mexico
ACTION AREA:	3	Ecology and Population Dynamics
LEAD ARRAY:	3.4	Determine origins of adult populations
OPTIM ARRAY:	3.4.2a	Identify and characterize source population zones
	3.4.2c	Determine regions in Mexico that may influence development of U.S. populations in the spring
DATES COVERED BY REPORT:		July 1993 – September 1997

PROGRESS REPORT: Corn earworm pheromone traps were deployed in the Lower Rio Grande Valley, Northeastern Mexico, and downwind throughout Texas during the blooming period for commercial citrus (approximately 25,000 acres) in the Lower Rio Grande Valley (LRGV). Five traplines were monitored in the downwind area for citrus pollen contamination of corn earworm adults during 1994. The North trapline extended from Falfurrias to Richland, TX. One citrus pollen contaminated moth was detected at the northernmost location (Richland), approximately 400 miles from the LRGV. Overall citrus pollen contamination for this trapline was 6.4 percent. The Southwest trapline extended from Crockett to San Marcos, TX. Two citrus pollen contaminated moths were collected at the easternmost location (Crockett), approximately 400 miles from the LRGV. Overall citrus pollen contamination was 5.7 percent. The Southeast trapline extended from Gatesville to Rosenberg, TX. Two citrus pollen contaminated moths were collected at the westernmost location (Gatesville), approximately 400 miles from the LRGV. The Western trapline extended from Laredo, TX to Las Cruces, NM. Traps in Laredo detected two citrus pollen contaminated moths; Del Rio and Uvalde, TX, locations each detected one citrus pollen contaminated moth. No citrus pollen contaminated moths were detected in New Mexico traps. Similarly, none were detected in Oklahoma. Trapline in the LRGV exhibited 39.2 percent citrus pollen contaminated moths; however, citrus pollen contamination for direct captured corn earworm moths in citrus groves exceeded 91 percent. Further, traps placed in the vicinity of citrus groves indicated 64 percent citrus pollen contamination. During 1995, the North, Southwest, and Southeast traplines were monitored with the addition of more traps in grid formation throughout Texas as well as the Mexico trapline (17 locations). Fourteen percent of moths examined statewide contained citrus pollen. Moths (72 percent) in the Mexico trapline were contaminated with various pollen taxa. Twenty-five percent of all Mexico moths analyzed possessed citrus pollen. Citrus contaminated moths were found at all locations during the citrus blooming period. In the Mexico trapline, the following locations captured high numbers of corn earworm adults: Valle Hermoso, General Teran, Abasolo, and Ebano. These locations are all in agriculturally productive areas.

FY97 & FY98 WORK PLANS: No further field work planned.

INVESTIGATOR'S NAME(S): J. F. Esquivel, D. W. Spurgeon, T. N. Shaver, J. R. Raulston, and P. D. Lingren

AFFILIATION & LOCATION: USDA-ARS, APMRU, College Station, TX
USDA-ARS, CIRU, Weslaco, TX

ACTION AREA: 3 Ecology and Population Dynamics

LEAD ARRAY: 3.4 Determine origins of adult populations

OPTIM ARRAY: 3.4.2e Determine pollen loads on adults to determine possible origin

DATES COVERED BY REPORT: July 1993 – September 1997

PROGRESS REPORT: Citrus pollen loads were quantified for direct captured corn earworm adults in Lower Rio Grande Valley citrus groves. Pollen loads were quantified as follows: rare, <10 grains; light, 11-25 grains; moderate, 26-100 grains; and heavy, >100 grains. Insects (n = 159) captured in 1994 possessing citrus pollen exhibited 11.9 percent rare, 58.5 percent light, 12.6 percent moderate, and 17.0 percent heavy pollen loads. Insects (n = 81) captured in 1995 possessing citrus pollen exhibited 19.8 percent rare, 74.1 percent light, and 6.1 percent moderate pollen loads. Studies were also conducted to evaluate pollen retention by adult corn earworm. Field-collected insects were placed in cages and sacrificed at 12 h intervals for 72 h. Laboratory-reared insects were exposed to citrus blooms for 12 h then placed in cages and sacrificed at 12 h intervals for 72 h. Citrus pollen contamination was observed at all sampling intervals for both groups of insects. For field-collected insects, no significant differences were observed between or within sexes. The high percentage of pollen retention at all sampling intervals may be attributed to the unknown age and feeding activity of field-collected insects. Prolonged exposure to citrus blooms may lead to increased feeding and result in higher pollen contamination or retention even though some grains may become dislodged at each feeding session. Laboratory-reared corn earworm adults exhibited differences in pollen retention between females (62.2 percent) and males (35.6 percent). Females exhibited differences within sex at 48 hr interval; however, the 72 hr interval was not significantly different from the 0 h interval. No differences were observed among the male sampling intervals. These data suggest that corn earworm adults can retain pollen for at least 72 h after feeding. Coupling these data with pollen load data, determining origin of migrant insects can be facilitated.

FY97 & FY98 WORK PLANS: No further field work planned.

INVESTIGATOR'S NAME (S): G. D. Jones

AFFILIATION & LOCATION: USDA-ARS, APMRU, College Station, TX

ACTION AREA: 3 Ecology and Population Dynamics

LEAD ARRAY: 3.4.2

SAFEGD ARRAY: 3.4.2e Determine pollen loads on adults to determine possible origin

DATES COVERED BY REPORT: July 1993 – September 1997

PROGRESS REPORT: Some anemophilous (wind pollinated) pollen grains are found on insects. Although, many anemophilous taxa are utilized by honeybees, butterflies, and other insects, many researchers consider anemophilous taxa to be accidental contaminants from other pollen types being in nectar, or from contamination of insects while trapped. The nectar from 30 trees of two citrus varieties, Rio Red grapefruit and Marrs orange, was examined for pollen. Trees were divided into eight regions and the nectar removed from flowers. Nectar was acetolyzed and three slides of each sample were made. Marrs orange was less contaminated with pollen (11 percent) than Rio Red grapefruit (25 percent). Of the pollen contaminated nectar, 87 percent was citrus pollen. Only one anemophilous type was found in the samples (1 percent). From the small percentage of pollen types other than citrus in the nectar, it is doubtful that corn earworm moths obtain anemophilous types from citrus nectar. To determine accidental pollen contamination while trapped, 20 corn earworm adults were placed into traps and left outside for 24 h, every week from March through November 1996. After 24 h, insects were sacrificed by freezing them. Scanning electron microscopy was used to examine the insects for pollen contamination. Only six percent of the moths were contaminated with pollen. No moths had more that two pollen types. In none of the samples did pollen contamination occur on more than two moths.

FY97 & FY98 WORK PLANS: There are no future plans to continue with this research.

INVESTIGATOR'S NAME (S): G. D. Jones, J. D. Lopez, Jr., and T. N. Shaver

AFFILIATION & LOCATION: USDA-ARS, APMRU, College Station, TX

ACTION AREA: 3 Ecology and Population Dynamics

LEAD ARRAY: 3.4.3

SUPL ARRAY: 3.4.3b Develop efficient marking techniques for tracing moth population origin

DATES COVERED BY REPORT: July 1993 – September 1997

PROGRESS REPORT: *Lycopodium clavatum* Linnaeus spores are not found on corn earworm moths. The outside of this spore contains hook-like structures that can become entangled in and on insects. Spores were placed into a prepared sugar solution to determine the feasibility of their use as a marker. Fresh spores did not mix with the sugar solution, but floated on the top. This problem was due to the low specific gravity of the spores and the high specific gravity of the sugar solution. To increase the specific gravity of the spores, they were chemically treated (acetolyzed). After acetolyzation, the spores were stirred into the sugar solution. Spores remained mixed in the sugar solution and did not float to the surface. Adult corn earworms were fed the sugar-spore solution to determine if the spores could be identified within the crop and rectal sac. Spores were found for three days after feeding in the crop and rectal sac. Field tests showed that this technique worked well for marking feral moths.

FY97 & FY98 WORK PLANS: There are no future plans to continue with this research.

INVESTIGATOR'S NAME(S): J. K. Westbrook, W. W. Wolf, P. D. Lingren, J. R. Raulston, J. D. Lopez, J. F. Esquivel, G. D. Jones, and J. H. Matis

AFFILIATION & LOCATION: USDA-ARS, APMRU, College Station, TX

ACTION AREA: 3 Ecology & Population Dynamics

LEAD ARRAY: 3.5 Determine impact of migrant populations in recipient regions

DATES COVERED BY REPORT: Aug. 1993–May 1997

PROGRESS REPORT: Predictive models for the date of mean catch and peak catch of adult male corn earworm in south-central Texas in June had r^2 values of 0.71 and 0.66, respectively, based on longitude and latitude as the most significant predictors. Dates of first catch of adult male corn earworms in the central U.S. during a four-year period were significantly correlated ($r^2 = 0.69$) with longitude and latitude. Common partial slope estimates for predicting the date when cumulative catch first exceeded 5 moths were 7.36 and -1.27 days/degree for latitude and longitude, respectively. Intercepts for the predictive equation of first catch varied by as many as 17 days. Corn earworm migrations from the LRGV in June and July may contribute to an estimated $2 million cost of insecticides to control corn earworm in pre-bloom cotton on the Texas High Plains in years of moderate populations. Progress has advanced to Year 4.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S): S. D. Pair

AFFILIATION & LOCATION: USDA-ARS, SCARL, Lane, OK

ACTION AREA: 3 Ecology and Population Dynamics

LEAD ARRAY: 3.5 Determine impact of migrant populations in recipient regions

DATES COVERED BY REPORT: July 1993 – September 1997

PROGRESS REPORT: Determined source areas and temporal sequence of corn earworm population movement from the Lower Rio Grande Valley (LRGV) to the Texas High Plains (Year 1). Compiled and published information from adult corn earworm source and recipient areas over several years which suggest substantial annual impact of migration from the LRGV upon the High Plains of Texas and adjacent states during June and July. Similarly, corn earworm produced from corn on the High Plains severely impacts local cotton during August and September (Year 2).

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S): J. D. Lopez, Jr.

AFFILIATION & LOCATION: USDA-ARS, APMRU, College Station, TX

ACTION AREA: 3 Ecology and Population Dynamics

LEAD ARRAY: 3.5 Determine impact of migrant populations in recipient regions

OPTIM ARRAY: 3.5.2 Determine spatial and temporal patterns of populations

DATES COVERED BY REPORT: July 1993 – September 1997

PROGRESS REPORT: Sex pheromone trapping data collected in the Brazos River Valley of the pattern of occurrence of both the corn earworm/bollworm and tobacco budworm when added to previous data provide about 15 years worth of data that are available for analysis relative to environmental factors and pattern of occurrence in other geographical areas.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S): J. L. Willers

AFFILIATION & LOCATION: USDA-ARS, CSRU, Mississippi State, MS

ACTION AREA: 3

LEAD ARRAY: 3.5.2

DATES COVERED BY REPORT: July 1993-August 1997

PROGRESS REPORT: Lead array 3.5.2 still current as currently stated; ***essentially goals stated are completed.*** Final paper of results needs to be finished. The efforts of this array led to development of LIS-BAYESIAN sampling design being refined and completed under lead array 3.9. Concepts learned here are being employed with the work on sampling fields in conjunction with spectral images as mentioned in Lead Array 3.9.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		J. K. Westbrook, W. W. Wolf, P. D. Lingren, J. R. Raulston, G. F. McCracken, J. D. Ward, S. Allen, and P. Yura
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	3	Ecology & Population Dynamics
LEAD ARRAY:	3.6	Migration technology
SAFEGD ARRAY:	3.6.2a	Characterize dispersal attributes of moth clouds arising from source areas
SUPPL ARRAY:	3.6.3a	Correlate meteorological parameters with insect transport during migration
SUPPL ARRAY:	3.6.2b	Develop climatological phenological atlas defining insect source areas
DATES COVERED BY REPORT:		August 1993–May 1997

PROGRESS REPORT: Instrumented superpressure balloons (tetroons) were tracked by the Argos satellite and by vehicle to mark the approximate path of corn earworms migrating from the Lower Rio Grande Valley (LRGV), South-Central Texas, and the Texas High Plains. Tetroons displaced a mean distance of 257 km/night from the LRGV with a standard deviation of 146 km. These trajectories were oriented toward a mean direction of 343 deg. (NNW) with a standard deviation of 23 deg. Moths migrating from mature corn in the LRGV attained a mean flight altitude of 404 m above ground level and established an insect cloud width of 43 km. Tetroons carrying radiomicrophones recorded searching and feeding echos of Mexican free-tailed bats, predators of corn earworm moths and other nocturnally-active insects, above 500 m altitude in central Texas in July. Dietary analyses of the stomach contents and guano of bats indicate a very high proportion of Lepidoptera in the late-night bat diet in June, coincident with the estimated arrival of corn earworms migrating from the LRGV. The aerial concentration of corn earworm-size radar targets was positively correlated with clear-air reflectivity measured by NEXRAD (WSR-88D) Doppler weather radars in south-central Texas. The flight speed of corn earworm-size radar targets was positively correlated with the difference between the Doppler velocity and wind velocity. An Australian Insect Monitoring Radar collected data from which to classify aerial targets by size, shape, altitude, airspeed, orientation, and heading relative to the wind direction. Nocturnal wind trajectories for the period of peak corn earworm emergence from mature corn in the LRGV were estimated for a six-year period and revealed two-night dispersion primarily throughout Texas and Oklahoma. The mean longitude of the trajectory endpoints ranged from 97.40 to 99.58 degrees, and the mean latitude ranged from 29.72 to 32.58 degrees within the six-year period. A Geographic Information System is being implemented with separate data layers for moth captures, climate, land use, crop type, and soil type for analysis of areawide insect population development and movement. Progress has advanced to Year 5 for most sub-arrays.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		K. R. Beerwinkle, P. D. Lingren, J. D. Lopez, Jr., P. G. Schleider, and R. S. Eyster
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	3	Ecology and Population Dynamics
LEAD ARRAY:	3.6	Migration technology
OPTIM ARRAY:	3.6.2a	Characterize dispersal attributes of moth clouds arising from source areas
OPTIM ARRAY:	3.6.2b	Develop and improve aerial sampling technology
SUPPL ARRAY:	3.6.3b	Correlate meteorological parameters with insect transport during migration
DATES COVERED BY REPORT:		July 1993–May 1997

PROGRESS REPORT: Nocturnal aerial insect flight activities between 30 and 900 m above ground level were monitored with 3-cm scanning radar during the spring, summer, and fall of two successive years in the Brazos River Valley of Burleson County near College Station, TX (Beerwinkle et al. 1994). Surface meteorological parameters were measured continuously with weather station instrumentation, and radiosondes carried aloft by weather balloons were used to measure upper-air temperatures and wind conditions. Aerial volume density patterns and flight behaviors observed with radar varied because of the many biological and meteorological variables involved, but certain seasonal characteristics of insect flight behavior became apparent during the course of the research. Nightly local dispersal flights at dusk were the norm, especially during the summer. Large numbers of insects were typically airborne for 1 to 2 h beginning about ½ h after sunset with some of them reaching altitudes of 800 m or more where wind speeds were typically greater than 30 km/h. Several apparent long-range migration-type insect movement events were observed in which insects were concentrated in layers in high-speed, low-level wind jets that were apparently associated with nocturnal upper-air temperature inversions. Migration-type movement of insects tended to be northward in the spring and early summer, and then southward in the fall.

Aerial insect densities were monitored continuously with an automated, vertically-oriented x-band radar system in the Brazos River Valley area of Burleson County, TX, during two successive years (Beerwinkle et al. 1995). The sensitivity of the radar system was such that noctuid-sized insects could be detected at a maximum altitude of about 2450 m. Aerial densities of flying insects were determined by automatic counting of radar-detected targets in 64 discrete range intervals spanning the altitude range from ground level to 2432 m. Insect densities were typically highest near ground level, they decreased nonlinearly with increasing altitude, and they were considerably reduced at altitudes above 800 m. There were apparent periodicities in the aerial densities during both years which were probably caused by interactions of the flight behaviors of several different insect species, insect reproduction cycles, and the effects of seasonal weather patterns. Some seasonal variations in radar-detected insect densities were apparently correlated with seasonal density variations of specific species determined by pheromone-baited traps in the area.

FY97 & FY98 WORK PLANS: No firm plans for further work in this area.

INVESTIGATOR'S NAME(S): J. L. Willers

AFFILIATION & LOCATION: USDA-ARS, CSRU, Mississippi State, MS

ACTION AREA: 3

LEAD ARRAY: 3.7

DATES COVERED BY REPORT: July 1993-August 1997

PROGRESS REPORT: Lead array 3.7 statements still current as currently stated. Further progress or changes are not able to occur until the fractional factorial designs mentioned in Lead array 3.8 are available.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S): J. L. Willers

AFFILIATION & LOCATION: USDA-ARS, CSRU, Mississippi State, MS

ACTION AREA: 3

LEAD ARRAY: 3.8

DATES COVERED BY REPORT: July 1993–September 1997

PROGRESS REPORT: Additional statistical methods applicable to the validation, verification, calibration, and analysis of deterministic simulation models have been developed. These techniques adapted from designs applicable to exploratory experiments having a single replication have proved useful. The SAS code to implement these methods is available for simulation experiments having two controllable input variables (e.g., $n = 2$ factors) at $m > 3$ levels, for 4-8 factors at two levels each, and for 3 factors at 3 levels each. These types of statistical tools are necessary to properly integrate plant and insects models that perform concurrently. These methods work with any deterministic, or stochastic (with slight modifications), model where the goal is to simultaneously explore the relationship among many controllable input variables upon the output that is produced by the run.

FY97 & FY98 WORK PLANS: Eventually, a statistical design employing fractional factorial concepts, and the supporting SAS code to implement the design, will be developed. When completed, simulation experiments involving large numbers of factors (8-20 factors) will be able to be properly analyzed.

INVESTIGATOR'S NAME(S): J. L. Willers

AFFILIATION & LOCATION: USDA-ARS, CSRU, Mississippi State, MS

ACTION AREA: 3 Ecology and Population Dynamics

LEAD ARRAY: 3.9 Develop optimum sampling procedures

DATES COVERED BY REPORT: July 1993 – September 1997

PROGRESS REPORT: The sampling protocol was revised by merging Line-Intercept sampling (LIS) techniques with Bayesian methods previously developed. LIS involves the use of belt transects (e.g., line transects having length and width) where samples are taken from all plants in a segment of row (typically, 3 feet) across a series of rows (from 4-32 rows, depending on the task). This combined sampling plan offers the advantage of being able to sample extremely low populations, but at some expense of time. Software to implement the new method is being designed. Economic populations are rapidly identified. Current data suggests that these plans detect field populations at lower densities than most other methods. The principal disadvantage is the need to use computer software. Under the constraint of the need to enter the data via the keyboard, the sampling system, as coded in the expert system WHIMS, is only convenient for a small number of fields and a small number of samples. The information transfer 'bottleneck' significantly interferes with development of databases across years with large farms when numerous fields are involved. The need for electronic, or automated sampling aids to reduce observer error and the time and labor of sampling remain. Limited progress has been made with the use of speech recognition software. Limitations in current methods to cope with interfering sounds, battery life and portability of computers able to withstand field conditions currently limit the promise of this technology. However, rapid changes in these areas are expected to eliminate these hindrances in the near future. Some limited explorations into devices to help detect insects on cotton plants (via sensors) have been accomplished; but, available funds to refine these tools limits progress. Collaborative ties between several research personnel and private industry exist and are in place to move these concepts forward once funds are secured.

FY 96 & FY97 WORK PLANS: Beginning with the 1997 field seasons, the sampling plans discussed above where combined with remote sensing images of a 200 acre cotton field (in cooperation with Mississippi State and the Stennis Remote Sensing Center). By using spectral images of the field, site specific sampling related to crop phenology could be accomplished. Early indications suggest that tremendous savings in sampling effort over large acreages can be accomplished by using spatially registered images of cotton fields. Preliminary work into use of adaptive sampling concepts in collaboration with such images is being pursued. Work is expected to continue in this direction in the near future, along with issues discussed above. Continue work to refine and make more user friendly appropriate software.

Note: R. A. Sequeira and M. R. Williams are no longer affiliated with CSRU.

INVESTIGATOR'S NAME(S): J. D. Lopez, Jr.

AFFILIATION & LOCATION: USDA-ARS, APMRU, College Station, TX

ACTION AREA: 3 Ecology and Population Dynamics

LEAD ARRAY: 3.9 Develop optimum sampling procedures

SAFEGD ARRAY: 3.9.1a Improve capabilities of estimating pest abundance from limited sample data

DATES COVERED BY REPORT: July 1993 – September 1997

PROGRESS REPORT: Plans for the construction of the Texas wire cone sex pheromone trap that is being used extensively to monitor activity and to collect samples of adult corn earworm/ bollworm and tobacco budworm were provided to a local commercial metal fabrication firm. Construction of the traps was monitored to ensure that the traps met construction specifications. This firm is now commercially building traps for researchers and producers. Techniques developed for the use of feeding attractants and stimulants with various dyes to mark adult moths should be useful in estimating adult pest abundance or activity.

FY97 & FY98 WORK PLANS:

Research Summary

Action Area III. Ecology & Population Dynamics

Compiled by: J. D. Lopez & J. K. Westbrook

Nine major research areas were identified for this action area in the ARS H/H Revised National Suppression Action Plan developed as part of a working conference held in San Antonio, TX, September 16-19, 1991, and published in February 1992. These areas identified as lead arrays were:

3.1 Quantify preflight activities
3.2 Determine adult response to plants and plant volatiles
3.3 Determine migratory and trivial flight initiation and termination
3.4 Determine origins of adult populations
3.5 Determine impact of migrant populations in recipient regions
3.6 Migration technology
3.7 Optimize rbWHIMS model for cotton production and protection
3.8 Integrate WHIMS and GOSSYM/COMAX
3.9 Develop optimum sampling procedures

Research progress related to each lead array follows:

Lead Array 3.1: Two different habitats, senescent corn and blooming citrus, were evaluated to observe adult corn earworm behavior presumably before migration and dispersal. Adult moths, especially females, utilize citrus blooms as a food source during early evening hours as determined by direct observation and contamination of the adults with citrus pollen. Captures of mating insects and a high proportion of mated females suggest that citrus groves are used as reproductive sites. Observation of large numbers of adults feeding during early evening on field-applied materials in senescent corn indicate that an as yet undetermined proportion of adults emerging the previous night remain in the corn and feed.

Lead Array 3.2: Adult corn earworms were attracted to flowering parts of 37 different plant species in laboratory olfactometer bioassays, confirming their polyphagous nature. A wide range of chemical constituents were identified from the different plant species. Olfactometer bioassays showed that five out of fourteen compounds originally identified from *Gaura drummondii* attracted adult corn earworms. Further testing and a patent application are being pursued under a CRADA with a major agricultural chemical corporation. Adult corn earworms were observed to feed extensively during each season on rye grass, *Lolium perenne*, infected with ergot, *Claviceps purpurea*, and containing honeydew. Adult corn earworms extended their proboscis in response to tarsal contact with numerous flowering herbs, trees, and grasses, which indicates that they are possible adult food plants. Young willow male and female flowers induced proboscis extension when nectaries were functional. A positive proboscis extension response to post oak catkins and sweet corn tassels was dependent on the presence of aphids/honeydew. Adult corn earworms and tobacco budworms responded to and fed on a combination of a feeding attractant from *Gaura* and a feeding stimulant applied to corn and cotton under field conditions. Phenylacetaldehyde and methyl salicylate volatilized from cotton dental rolls were detected at 5 m but not at 10 m radial distances from the source when sampled by vacuum air pumps pulling air through absorbent media (tenax and charcoal) for 10 hour nightly periods. About 75 percent of the phenylacetaldehyde and methyl salicylate was released during 10 hours from three cotton dental wicks which contained 88 mg of each chemical. Maximum and minimum nocturnal wind speed in a 1.5 m high corn canopy was at 2.25 and 0.75 m respectively. Minimum air temperature was at 1.65 m. RH was greater at 0.75 m than at 3.0 m.

Lead Array 3.3: Scanning radar measurements of corn earworm size targets in the Lower Rio Grande Valley indicated: flight at a mean airspeed of 5 m/s, heading 13 degrees clockwise relative to wind displacement; flight initiation at 0.5 h after sunset with peak at 1.25 h after sunset; collective alignment in May and June (84 nights) during a 6 year period; angular difference between collective alignment and wind displacement 30 degrees during 85 percent of nights with collective alignment for more than 1 h and within an atmospheric layer at least 200 m depth; and collective alignment perpendicular to a southeast wind direction. In the Texas High Plains in August, individual flight trajectories were variable, which indicated a significant

biological component to population dispersal, mean flight speed of 4.5 m/s and mean heading of 25 degrees counterclockwise to wind displacement direction.

Lead Array 3.4: Research determined the parameters governing population dynamics on corn in the Lower Rio Grande Valley (LRGV), quantified potential adult production, defined weather-related transport, and characterized the temporal sequence of population development with movement into the LRGV, Uvalde, and Lubbock. Continuous sex pheromone trapping of corn earworm and tobacco budworm in the Brazos River Valley since the late 1970's has provided a database that can be used to evaluate the effect of various factors on the temporal occurrence of both species. Considerable progress was made on the use of pollen in determining the origin of migrating adult corn earworms. A pollen reference collection was started at the Areawide Pest Management Research Unit (APMRU), College Station, TX, in 1994, and now contains pollen from 1,000 entomophilous (insect pollinated) taxa collected in Texas, other states, and Mexico. Three other pollen reference collections on loan to APMRU are the Stanley D. and Gretchen D. Jones collection, Meredith Hoag Lieux collection, and David Jarzen collection. There are 7,500 worldwide taxa represented in the four collections that are available for pollen research and identification. Examination of corn earworm males captured in sex pheromone traps operated in the LRGV, northeastern Mexico, and downwind throughout Texas during the blooming period for commercial citrus in the LRGV during 1994 and 1995 indicated that citrus contaminated moths were captured as far north as Richland, Crockett, Gatesville, Del Rio, and Uvalde (up to 400 miles from the LRGV), no citrus contaminated moths in New Mexico and Oklahoma, and relatively high percentages of citrus contaminated moths in Mexico and the LRGV. Examination of corn earworms captured in citrus groves during 1994 and 1995 in the LRGV indicated that about 80 to 90 percent of the adults carried pollen loads of 11 or more pollen grains. Other studies with field-collected and laboratory-reared adult corn earworms suggested that the adults can retain citrus pollen for at least 72 h after feeding. Because only one percent of nectar samples collected from 30 trees of Rio Red grapefruit and Marrs orange were contaminated with anemophilous pollen, it is doubtful that corn earworm moths obtain anemophilous pollen from citrus nectar. Only six percent of adult corn earworms placed in a trap for 24 h periods between March and November 1996, were contaminated with pollen, no moths had more than two pollen types and none of the samples of 20 moths had more than two moths contaminated with pollen. These results indicate that accidental contamination of moths in traps is minimal. Entomological radar indicated a comparable concentration of airborne insects from Edinburg to Del Rio, suggesting a large source of migrant corn earworms in Mexico in March. Acetolyzed *Lycopodium clavatum* spores which are not found in or on corn earworm moths when mixed with a feeding stimulant solution and fed to the moths effectively marked the moths for up to three d by their presence in the crop and rectal sac. Field tests showed this technique could be used for marking corn earworms emerging from senescent corn. A small scale mark and recapture test with the spores in the LRGV showed that marked moths were captured in pheromone traps as far as 230 km north during the period of peak corn earworm emergence in June. Pheromone trap capture events throughout Central Texas during periods of suspected migration were well correlated with estimated insect flight trajectories from the LRGV and local minimum temperature. Calculated insect flight trajectories for citrus pollen containing corn earworm moths captured in Oklahoma in the spring of 1990 following a severe freeze in the LRGV that devastated citrus production, indicated that Florida, the Bahamas, Cuba, Yucatan Peninsula, or Northern Central America were possible source areas. Various dyes have been evaluated for marking corn earworm adults when mixed with a feeding stimulant and some have been identified which do not interfere with feeding and provide a suitable mark.

Lead Array 3.5: Dates of first catch of male corn earworms in the central U. S. during a four year period were significantly correlated with longitude and latitude. Longitude and latitude were also the most significant predictors for the date of mean and peak catch of male corn earworms in south central Texas in June. Information were compiled and published from adult corn earworm source and recipient areas over several years which suggest substantial annual impact of migration from the LRGV upon the Texas High Plains and adjacent states during June and July. Corn earworms produced from corn in the High Plains severely impacts local cotton during August and September. Final paper for results needs to be finished. Research led to development of a Line-Intercept Sampling (LIS) Bayesian sampling design for determining spatial patterns of insect population. Concepts learned here are being used in sampling fields for analysis of spectral images. Goals of Optimum Array 3.5.2 have been completed.

Lead Array 3.6: Instrumented superpressure balloons (tetroons) tracked by Argos satellite and vehicle to mark the appropriate path of corn earworms migrating from the LRGV, south-central Texas, and the Texas High Plains indicated mean distance displacement of 257±146 km/night from the LRGV, and trajectories oriented toward a mean (±SD) direction of 343(±23) degrees (NNW). Migratory moth clouds originating from mature corn in LRGV were at a mean flight altitude of 404 m above ground level and had a width of 43 km. Research showed that Mexican free-tailed bats may be important predators of migratory corn

earworms and other Lepidoptera. Initial evaluation indicated that NEXRAD (WSR-88D) Doppler weather radars may be important in studying corn earworm migration. Mean longitude and latitude of two night trajectory endpoints from mature corn in the LRGV ranged from 97.40 to 99.58 and 29.72 to 32.58 degrees respectively, over a six year period. A GIS system is being implemented for use in insect migration research. Scanning radar detection of nocturnal aerial insect flight activities between 30 and 900 m AGL over two years indicated nightly local dispersal flights at dusk especially during the summer, large numbers of insects typically airborne for 1 to 2 h starting about one half hour after sunset and with flight altitudes up to 800m where windspeeds were typically greater than 30 km/h, several apparent long-range insect migration type events with insects concentrated in layers in high-speed, low-level wind jets, and migration-type insect movements northward in spring and early summer, and then southward in the fall. An automated, vertically oriented x-band radar system operated during two years indicated considerably reduced insect densities at altitudes above 800m, apparent periodicites in aerial densities probably caused by interactions of flight activities of different insect species, reproduction cycles, effects of seasonal weather patterns, and apparent correlation of radar-detected insect densities with seasonal activity variations of specific species detected by sex pheromone traps in the test area.

Lead Array 3.7: Further progress is pending the development of fractional factorial designs.

Lead Array 3.8: Additional statistical methods have been developed for the validation, verification, calibration and analysis of deterministic simulation models. These techniques have been adapted from designs used for exploratory experiments with a single replication. SAS software implementation of these methods has been developed for simulation experiments having two controllable input factors at more than 3 levels for 4 to 8 factors at 2 levels each, or 3 factors at 3 levels each. These methods work with any deterministic or stochastic (with slight modifications) model for simultaneous exploration of the relationship among many controllable input variables and the model output.

Lead Array 3.9: The sampling protocol was revised by merging Line-Intercept Sampling (LIS) techniques with Bayesian methods previously developed. LIS involves the use of belt transects (i.e., line transects having length and width) where samples are taken from all plants in a segment of row (typically, 3 feet) across a series of rows (from 4 to 32 rows, depending on the task). Current data suggest that these plans detect field populations at lower densities than most other methods. The principal disadvantage is the need to use computer software. Under the constraint of the need to enter the data via the keyboard, the sampling system as coded in the expert system WHIMS, is only convenient for a small number of fields and a small number of samples. The information transfer 'bottleneck' significantly interferes with development of databases across years when large farms or numerous farms are involved. Electronic, or automated, sampling aids are needed to reduce the time, labor, and error associated with observer sampling, where limited progress has been made using speech recognition software. Some limited explorations of sensors which detect insects on cotton plants have been accomplished, but available funds limit progress to refine these tools. Site-specific sampling plans discussed above and adaptive sampling concepts were combined with remote sensing (spectral) imagery to assess the crop phenology of a 200-acre cotton field in cooperation with Mississippi State University and the Stennis Remote Sensing Center. Early indications suggest that tremendous savings in sampling effort over large areas can be accomplished by using spatially-registered images of cotton fields.

Progress Report

Action Area IV. Behavior Modifying Chemicals

Coordinators: T. N. Shaver & J. A. Klun

INVESTIGATOR'S NAME(S):		J. D. Lopez, Jr., T. N. Shaver, and K. R. Beerwinkle
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	4	Behavior Modifying Chemicals
LEAD ARRAY:	4.1	Develop and implement methods to manage H/H populations in cropping systems with plant derived allelochemicals
SAFEGD ARRAY:	4.1.1	Develop oviposition attractants and stimulants as tools for monitoring H/H
OPTIM ARRAY:	4.1.2	Combine oviposition attractants with sex pheromone to monitor and/or manage both sexes
DATES COVERED BY REPORT:		July 1993 – September 1997

PROGRESS REPORT: As a continuation of a research project started in the 1980s to identify oviposition stimulants for the tobacco budworm from chickpeas, seed of different chickpea varieties planted in the U.S. (Idaho, Washington, and California) for commercial production have been obtained and have been planted in Texas. These varieties have been evaluated for ability to grow in the local area and to attract wild tobacco budworm. Several varieties have been identified and are being studied further as sources of volatile oviposition attractants/stimulants.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		J. K. Westbrook
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	4	Behavior Modifying Chemicals
LEAD ARRAY:	4.1	Develop and implement methods to manage H/H populations in cropping systems with plant derived allelochemicals
SAFEGD ARRAY:	4.1.1	Develop oviposition attractants and stimulants as tools for monitoring H/H
OPTIM ARRAY:	4.1.2	Develop oviposition attractants and stimulants as tools for monitoring H/H
SUPPL ARRAY:	4.1.2	Develop methods to determine whether allelochemicals of plant origin work in concert with plant source radiation to attract H/H
DATES COVERED BY REPORT:		August 1993 - May 1997

PROGRESS REPORT: No progress reported.

INVESTIGATOR'S NAME(S):		T. N. Shaver and J. D. Lopez
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	4	Behavior Modifying Chemicals
LEAD ARRAY:	4.1	Develop and implement methods to manage H/H populations in cropping systems with plant derived allelochemicals
SAFEGD ARRAY:	4.1.1	Develop oviposition attractants and stimulants as tools for monitoring H/H
DATES COVERED BY REPORT:		August 1993 - May 1997

PROGRESS REPORT: Ovipositional response of tobacco budworm to chickpea (garbanzo bean) (*Cicer arietinum* L.) was determined using fruiting terminals and methylene chloride extracts of fruiting terminals. Results of the tests demonstrated that chickpea contains a chemically-mediated oviposition stimulant/attractant that can be extracted with methylene chloride. Observations of small plots of chickpea planted under field conditions indicated that large populations of tobacco budworm larvae accumulate.

FY97 & FY98 WORK PLANS: Identify chemicals from various varieties of chickpea and test chemicals and mixtures of chemicals as oviposition attractants and stimulants in laboratory and field settings.

INVESTIGATOR'S NAME(S):		J. D. Lopez, Jr. T. N. Shaver, and K. R. Beerwinkle
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	4	Behavior Modifying Chemicals
LEAD ARRAY:	4.2	Develop and implement methods to suppress H/H populations with attracticide (allelochemical) baits for adults
OPTIM ARRAY:	4.2.2a	Select effective chemical toxicants and formulations for adults that do not interfere with the efficiency of the attractant
DATES COVERED BY REPORT:		July 1993–September 1997

PROGRESS REPORT: Intensive evaluations of carbohydrate food sources in the laboratory and field have identified a strong feeding stimulant that induces adult feeding by corn earworm/ bollworm and tobacco budworm under field conditions. This feeding stimulant when combined with a feeding attractant and applied to corn or cotton has been shown to attract both species and to induce them to feed in treated areas. Screening of numerous commercially available insecticides for their effects on feeding response and mortality of adult corn earworms when mixed with a feeding stimulant has identified several insecticides that are compatible with the stimulant in inducing feeding and are also highly toxic when ingested. Field evaluations of some of these insecticides when used in combination with a feeding attractant and a stimulant have also shown that adults can be killed with lower concentrations of active ingredient than are recommended for larval control.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S): E. R. Mitchell

AFFILIATION & LOCATION: USDA-ARS, CMAVE, Gainesville, FL

ACTION AREA: 4 Behavior Modifying Chemicals

LEAD ARRAY: 4.3 Develop and implement methods to use pheromone mating disruption as an economically effective and reliable strategy for managing H/H species

DATES COVERED BY REPORT: June 1993-October 1996

PROGRESS REPORT: Different pheromone blends and formulations provided by Shin-Etsu Chemical Company, Tokyo, Japan, were evaluated in cotton as mating disruptants for *Heliothis virescens* and *Helicoverpa zea*. Screening trials were conducted in small plots of 0.25 acre ea. The most effective formulations later were used to treat large fields ranging in size from 25 to 200 ac. Shin-Etsu rope dispensers were applied at rates ranging from 200-800 per ac. Treatment efficacy over time was measured by (1) reductions in moth captures in pheromone-baited wire-cone traps, (2) reductions in mating by sentinel females (8-10) placed on mating tables positioned near the center of the pheromone-treated areas, and (3) weekly counts of eggs, larvae, and damaged fruit (large-scale field trials only). All evaluation criteria were compared to results in similar untreated (i.e., no pheromone treatment applied) cotton plots or fields located nearby.

The most effective pheromone treatment was a blend of Z-11-hexadecenal/Z-9-hexadecenal/Z-9-tetradecenal in a 15:1:1 ratio. This blend at 400 dispensers per acre was slightly more effective against *H. virescens* than *H. zea*. However, treatment efficacy from year-to-year was extremely variable, and none of the pheromone formulations evaluated were effective in large-scale trials for more than a few weeks.

FY97 WORK PLANS: Small plot field trials will be conducted using extremely high dosages of pheromone evaporated from few super sites per acre.

INVESTIGATOR'S NAME(S):		J. D. Lopez, Jr., T. N. Shaver, and K. R. Beerwinkle
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	4	Behavior Modifying Chemicals
LEAD ARRAY:	4.4	Develop and implement methods for using semiochemicals to improve estimates of H/H populations and detect exotic species
SAFEGD ARRAY:	4.4.1	Determines attractiveness of allelochemicals to other economic lepidopterous pests
OPTIM ARRAY:	4.4.2	Develop effective trapping systems
DATES COVERED BY REPORT:		July 1993–September 1997

PROGRESS REPORT: Feeding of adult corn earworms on various dyes when mixed with a feeding stimulant at relatively low concentrations has shown that this technique may be useful in marking feral adults. Such a marking technique should be useful in conjunction with a feeding attractant to mark large numbers of feral moths in specific situations for use in mark and recapture studies to evaluate adult densities. Other species of noctuids such as cabbage and soybean loopers, black cutworms, true armyworms, fall armyworms, and beet armyworms have been observed to respond under field conditions to feeding attractant or stimulant applications. A collapsible cone sex pheromone trap made of netting material and designed by researchers in Australia as an improvement of the Scentry® cone trap was compared to Texas wire cone and Scentry® traps for efficacy in capturing adult corn earworms. The Australian trap was equal in efficacy to the Scentry® trap and significantly less effective than the Texas wire cone trap.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		J. K. Westbrook
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	4	Behavior Modifying Chemicals
LEAD ARRAY:	4.2	Develop and implement methods to suppress H/H populations with attracticide (allelochemicals) baits for adults
SAFEGD ARRAY:	4.2.1	Determine whether plant-derived kairomone attractants enhance the efficiency of pheromone traps for capturing H/H
OPTIM ARRAY:	4.2.2a	Select effective chemical toxicant and formulation for adults that do not interfere with the efficiency of the attractant
DATES COVERED BY REPORT:		August 1993 - May 1997

PROGRESS REPORT: No progress reported.

INVESTIGATOR'S NAME(S): J. K. Westbrook and T. N. Shaver

AFFILIATION & LOCATION: USDA-ARS, APMRU, College Station, TX

ACTION AREA: 4 Behavior Modifying Chemicals

LEAD ARRAY: 4.4 Develop and implement methods for using semiochemicals to improve estimates of H/H populations and detect exotic species

SAFEGD ARRAY: 4.4.1 Determine attractiveness of allelochemicals to other economic lepidopterous pests

DATES COVERED BY REPORT: August 1993 - May 1997

PROGRESS REPORT: Vacuum air pumps sampled approximately 0.5 m^3 of air through adsorbent media (tenax and charcoal) and were collected for 10 h nightly periods. Eighty-eight milligrams each of phenylacetaldehyde (PA) and methylsalicylate (MS) were applied in solution to each of three cotton dental rolls. PA and MS were released from cotton rolls at rates of 80 percent and 73 percent, respectively, per 10 h nocturnal period. The maximum concentration of PA adsorbed in a column at the volatile source was 3.1538 mg/m^3 for PA and 0.8749 mg/m^3 for MS. Maximum concentrations of 0.0177 mg/m^3 and 0.0071 mg/m^3 were collected at a radial distance of 5 m from the volatile release location for PA and MS, respectively. Concentrations of PA and MS greater than 0.0001 mg/m^3 were detected at heights of 0.1 m and 1.5 m (top of corn canopy). No PA or MS was detected in vacuum air samples at a radial distance of 10 m from the volatile source. Maximum nocturnal wind speed was at 1.5 H, where H is the canopy height (approx. 1.5 m). Minimum nocturnal wind speed was at 0.5 H. Nocturnal minimum air temperature was located at 1.1 H. Nocturnal relative humidity at mid-canopy (0.5 H) was greater than that above (2 H) the canopy. Progress has advanced to Year 4; more efficient air sampling and wind measurement is underway in 1997.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		T. N. Shaver, J. D. Lopez, H. F. Marshall, and K. R. Beerwinkle
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	4	Behavior Modifying Chemicals
LEAD ARRAY:	4.2	Develop and implement methods to suppress H/H populations with attracticide (allelochemicals) baits for adults
DATES COVERED BY REPORT:		August 1993 - May 1997

PROGRESS REPORT: Previously, flowers of *Gaura drummondii*, *G. suffulta*, and *G. longiflora* were reported as attractive to H/H, and 12, 21 and 25 compounds were identified from hexane extracts of the respective *Gaura* species flowers. Flowers from these three *Gaura* species were collected throughout the nighttime hours and were extracted with hexane or methylene chloride. Extracts were analyzed by GC or GC-MS to determine amounts of the various chemicals throughout the night. Headspace volatile collections were made from these three *Gaura* species during nighttime hours by pulling air over intact plants and trapping volatile chemicals on a suitable adsorbent. Generally, amounts of chemicals in both extracts and headspace volatile collections were greatest about one hour after onset of darkness until about five hours later, and then amounts decreased until daylight. Three compounds that had not been previously identified from *G. drummondii* were identified in the solvent extracts.

FY 97 WORK PLANS: Baits will be formulated using chemicals identified from the three *Gaura* species so the chemicals will be emitted at concentrations and ratios similar to those determined from headspace volatile collections from these plants during the early part of the night when there is a major feeding period of H/H adults. These baits will be tested in traps and in field plots to determine attractiveness to field populations of H/H.

INVESTIGATOR'S NAME(S):		T. N. Shaver, J. F. Esquivel, J. D. Lopez, H. F. Marshall, and K. R. Beerwinkle
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	4	Behavior Modifying Chemicals
LEAD ARRAY:	4.4	Develop and implement methods for using semiochemicals to improve estimates of H/H populations and detect exotic species
DATES COVERED BY REPORT:		August 1993 - May 1997

PROGRESS REPORT: Chemical baits based on chemicals identified from plants attractive to corn earworm and that showed activity in laboratory olfactometers to corn earworm adults were tested in standard wire cone traps placed in alfalfa fields or in pasture land adjacent to maturing or harvested cotton. Some mixtures of chemicals captured both sexes of corn earworm and tobacco budworm moths in approximately equal amounts, although trap captures were relatively low. Greater numbers of soybean looper and cabbage looper males and females were attracted to traps baited with chemical blends. Based on attractiveness of these chemical mixtures to corn earworm adults in olfactometers, the potential exists to improve effectiveness of the chemical attractants in traps by formulating chemical blends that more nearly mimic blends actually surrounding attractive plants, especially during nighttime hours when noctuid adults are likely to be in a major feeding period.

FY 97 WORK PLANS: Chemical blends will be formulated based on chemical analyses of headspace volatile collections from attractive field plants during the peak feeding period of corn earworm moths. These blends will be tested for activity in wire cone traps throughout the year in differing cropping systems.

INVESTIGATOR'S NAME(S):		T. N. Shaver, J. D. Lopez, J. F. Esquivel, and H. F. Marshall
AFFILIATION & LOCATION:		USDA-ARS, APMRU, College Station, TX
ACTION AREA:	4	Behavior Modifying Chemicals
LEAD ARRAY:	4.7	Develop and implement strategies for using semiochemical-enhanced parasites/predators to achieve economical, effective and reliable biological control of H/H
DATES COVERED BY REPORT:		August 1993 - May 1997

PROGRESS REPORT: During work on a long term project to develop an adult control system for H/H, we noted that some mixtures of chemicals identified from plants attractive to noctuids were also attractive to *Chrysoperla* species. Chemical baits were tested for attraction to *Chrysoperla* spp. in standard wire cone pheromone traps placed in alfalfa, sorghum, cotton fields or in pasture land adjacent to maturing or harvested cotton during August to October. Also, sweep net sampling of *Chrysoperla* was conducted on several of the same nights that chemical lures were tested to verify the presence and relative abundance of *Chrysoperla* species and to determine sex ratios of these insects in the field populations. During August and early September more than 80 percent of Chrysopidae captured in chemical baited traps were *C. carnea* females while less than 20 percent of those captured in sweep nets were *C. carnea* females. During this period a total of 7,213 *Chrysoperla* spp. were captured for an average of 34.3 per trap night while less that 0.1 *Chrysoperla* spp. were captured per trap night in unbaited traps. It appears that the chemical baits used in these tests are more attractive to *C. carnea* females than to *C. carnea* males or *C. rufilabris* males and females.

FY97 & FY98 WORK PLANS: During the next year we will test other chemicals for attraction to *Chrysoperla* spp. and test possibility of using attractive chemical blends to recruit and conserve natural populations of *Chrysoperla*.

INVESTIGATOR'S NAME(S): S. D. Pair, William Schlotzhauer, and Bob Horvat

AFFILLATION & LOCATION: USDA-ARS, SCARL, Lane, OK, and USDA-ARS, Athens, GA

ACTION AREA: 4 Behavior Modifying Chemicals

LEAD ARRAY: 4.2 Develop and implement methods to suppress H/H populations with attracticide (allelochemicals) baits for adults

DATES COVERED BY REPORT: 1993-1997

PROGRESS REPORT: Japanese honeysuckle (JHF) was discovered as an ovipositional and adult food host of *Heliothis virescens* and *Helicoverpa zea* (Year 2 & 3). However, JHF appears more attractive to tobacco budworm than to bollworm. Hartstack traps baited with bouquets of Japanese honeysuckle flowers also attracted a wide range of adult noctuids including cabbage and soybean looper, velvetbean caterpillar, H/H, and sphingids such as the tomato/ tobacco hornworm complex. Of 27 compounds detected in JHF, three volatiles were identified as major components of JHF that were attractive to moths. Traps baited with dental wicks saturated with a mixture of the three chemicals were as effective in attracting moths as traps baited with JHF bouquets (Years 3&4).

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		P. J. Landolt and E. R. Mitchell
AFFILIATION & LOCATION:		USDA-ARS, CMAVE, Gainesville, FL
ACTION AREA:	4	Behavior Modifying Chemicals
LEAD ARRAY:	4.2	Develop and implement methods to suppress H/H populations with attracticide (allelochemical) baits for adults
DATES COVERED BY REPORT:		June 1993-October 1996

PROGRESS REPORT: Tests were conducted in a laboratory flight tunnel and a small field cage to determine if *Heliothis virescens* moths are attracted to and can be trapped with fermented sweet baits. Jaggery, a palm sugar extract, was used as the sweet bait. Male moths released into a field cage were recaptured in traps baited with aged 10 percent jaggery. Both male and female moths were attracted to aged 10 percent jaggery in a flight tunnel, exhibiting oriented flights ending in contact with the bait. Although the bait initially was not attractive either to females in a flight tunnel or to males in a field cage, it subsequently became attractive after one week and increased in attractiveness for up to 24 days after it was made. This is the first report of oriented responses of *H. virescens* to food baits. Microbial activity appears to be a critical factor in moth attraction to the jaggery sweet baits.

FY97 WORK PLANS: Volatiles from fermented jaggery solutions have been collected. Laboratory assays and field trapping studies will be conducted to determine the attractiveness of various volatile fractions to *H. virescens* and *H. zea*.

Research Summary

Action Area IV. Behavior Modifying Chemicals

Compiled by: T. N. Shaver & J. A. Klun

Several long-range critical research needs were identified at an earlier workshop for research concerning behavior modifying chemicals for suppression of H/H populations: 1) Develop and implement methods for using kairomonal compounds derived from plants to suppress H/H populations in cropping systems via direct control of adults or indirectly through control of oviposition; 2) Develop and implement methods for suppression of H/H populations using a) sex attractant pheromones to disrupt mating via permeation of the atmosphere; b) combinations of pheromones, plant-derived kairomones, and toxicants to kill adults, and/or c) attracticide baits in traps to provide improved methods for forecasting and predicting H/H populations; 3) Suppress H/H via interference with pheromone biosynthesis, neuroendocrine, and olfactory systems; and 4) Develop and implement methods to use semiochemicals to enhance performance of insect parasitoids as economically effective and reliable control agents in management strategies for H/H species. A total of seven lead arrays with associated safeguard, optimizing, and supplemental arrays were developed to identify research areas to meet these long-range critical needs.

LEAD ARRAY 4.1: Some progress has been made toward developing and implementing methods to manage H/H populations with plant derived allelochemicals using oviposition attractants and stimulants for monitoring H/H. Ovipositional response of tobacco budworm to chickpea (garbanzo bean) (*Cicer arietinum* L.) was demonstrated using fruiting terminals. Results indicated that chickpea contains a chemically-mediated oviposition stimulant/attractant that can be extracted with methylene chloride. Seed of different chickpea varieties planted in the U.S. (Idaho, Washington, and California) for commercial production have been obtained and have been planted in Texas. These varieties have been evaluated for ability to grow in local area and to attract wild tobacco budworm. Several varieties have been identified that grow well in Texas and that accumulate large populations of tobacco budworm. These varieties are being studied further as sources of volatile oviposition attractants/stimulants.

No progress was reported on Optimizing array 4.1.2 to combine oviposition attractants with sex pheromone to monitor and/or manage both sexes of H/H.

LEAD ARRAY 4.2: Significant progress has been made in developing and implementing methods to suppress H/H populations with attracticide (allelochemicals) baits for adults. Japanese honeysuckle was discovered as an ovipositional and adult food host of *Heliothis virescens* and *Helicoverpa zea* as well as other adult noctuids including cabbage and soybean looper, velvetbean caterpillar, and sphingids such as the tomato/tobacco hornworm complex. A mixture of three of the 27 compounds identified form Japanese honeysuckle were as effective in attracting moths to traps as bouquets containing flowers of the plant.

Flowers were collected from *Gaura drummondii*, *G. suffulta*, and *G. longiflora* throughout the nighttime hours for extraction with solvent and headspace volatiles to determine volatile content and emission of volatiles from these attractive plants during times when H/H adults were actively feeding. Generally, amounts of chemicals in both extracts and headspace volatile collections were greatest about one hour after onset of darkness until about five hours later, and then amounts decreased until daylight. Three compounds that had not been identified previously from *G. drummondii* were identified in the solvent extracts.

Both males and female moths were attracted to aged 10 percent jaggery (a palm sugar extract) in a flight tunnel, exhibiting oriented flights ending in contact with the bait. Also, male tobacco budworm moths released into a field cage were recaptured in traps baited with aged 10 percent jaggery. The bait initially was not attractive either to females in a flight tunnel or to males in a field cage, but became attractive after one week and increased in attractiveness for up to 24 d after it was made. Microbial activity appears to be a critical factor to this attraction.

A strong feeding stimulant was identified that induces feeding in corn earworm and tobacco budworm under field conditions. This feeding stimulant when combined with a feeding attractant and applied to cotton or corn attracts both species and induces them to feed. Several insecticides have been identified that are compatible with the stimulant and are also highly toxic to the adult insects when ingested. Combinations of some of these insecticides with the feeding stimulant in field evaluations resulted in adult kill at lower concentrations of active ingredient than are recommended for larval control.

LEAD ARRAY 4.3: Some progress has been made in developing and implementing methods to use pheromone mating disruption as an economically effective and reliable strategy for managing H/H species. Pheromone blends and formulations were evaluated in cotton as mating disruptants for *Heliothis virescens* and *Helicoverpa zea*. Screening trials were conducted in 0.25 acre plots, and the most effective formulations were tested in 25 to 200 acre plats. The most effective pheromone treatment was a blend of Z-11-hexadecenal/Z-9-hexasecenal/Z-9-tetradecenal in a 15:1:1 ratio. This blend at 400 dispensers per acre was slightly more effective against *H. virescens* than *H. zea*. Treatment efficacy was extremely variable from year to year and none of the formulations were effective in large-scale trials for more than a few weeks.

No progress was reported to develop mechanized methods compatible with grower operations for distributing pheromone formulation or to evaluate selected non-pheromone chemicals as potential mating disruptants.

LEAD ARRAY 4.4: Considerable progress was reported in developing and implementing methods to improve estimates of H/H populations and detect exotic species. Feeding of adult corn earworms on various dyes when mixed with a feeding stimulant has shown potential in marking feral adults and may be useful in mark and recapture studies to evaluate adult densities. Noctuid species such as cabbage and soybean loopers, black cutworms, true armyworms, fall armyworms, and beet armyworms have been observed to respond under field conditions to feeding attractant or stimulant applications. In field traps, attractant baits captured low numbers of corn earworm and tobacco budworm moths of both sexes and in approximately equal numbers. Greater numbers of soybean and cabbage looper males and females were attracted to traps baited with chemical blends.

LEAD ARRAY 4.5: No progress was reported to develop methods to interfere with neuro-endocrine control of pheromone biosynthesis in H/H species.

LEAD ARRAY 4.6: No progress was reported to develop methods to disrupt the enzymatic systems in the pheromone biosynthetic pathway to suppress pheromone production.

LEAD ARRAY 4.7: Some progress was reported on developing and implementing strategies for using semiochemical-enhanced parasites/predators to achieve biological control of H/H. Chemical baits were attractive to *Chrysoperla* species, especially female *C. carnea* in cone traps, as evidenced by captures of approximately 35 per night compared to less than 0.1 per night in unbaited traps.

Progress Report

Action Area V. Biological Control

Coordinators: D. A. Streett & P. G. Tillman

INVESTIGATOR'S NAME(S): M. R. Bell and D. A. Streett

AFFILIATION & LOCATION: USDA-ARS, SIML, Stoneville, MS

ACTION AREA: 5 Biological Control

LEAD ARRAY: 5.1 Develop technology for managing H/H spp. using entomopathogens/nematodes

DATES COVERED BY REPORT: November 1993-May 1997

PROGRESS REPORT: The *Helicoverpa zea* nuclear polyhedrosis virus (HzNPV) has been used in the Mississippi Delta from 1993 to 1997 as a preventative suppression tactic to manage tobacco budworm and bollworm populations during the first generation. Application of HzNPV in all of the management programs thus far has resulted in a substantial prevalence of infection among larvae and a reduction in adult numbers emerging from treated areas compared with untreated areas. Future studies will evaluate the impact of lower virus application rates and virus enhancing factors providing adequate suppression of the pest population.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S): Thomas A. Coudron

AFFILIATION & LOCATION: USDA-ARS, BCIRL, Columbia, MO

ACTION AREA: 5 Biological Control

LEAD ARRAY: 5.1 Develop technology for managing H/H spp. using entomopathogens/nematodes

DATES COVERED BY REPORT: November 1993-May 1997

PROGRESS REPORT: Venom have been identified from eulophid species that differ in host range, but collectively regulate the development of most lepidopteran larvae and several coleopteran hosts. Minute [nanogram] quantities of a purified component (native molecular weight of ca. 66 kDa) from the venom of *E. comstockii* is able to arrest the larval-larval ecdysis process in *Trichoplusia ni* [used as a model insect host in these studies] and is likely to be effective in several lepidopteran species. Significant improvement of virosis was observed with AcMNPV in the presence of venomous material. Experiments are underway to isolate the gene for this novel developmental arrestant.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S): Gary W. Elzen

AFFILIATION & LOCATIONS: USDA-ARS, SARC, Beneficial Insect Research Unit, Weslaco, TX

ACTION AREA: 5 Biological Control

LEAD ARRAY: 5.1 Develop technology for managing H/H spp. using entomopathogens/nematodes

DATES COVERED BY REPORT: November 1993-May 1997

PROGRESS REPORT: Significant resistance to *Bacillus thuringiensis* Berliner was observed in one strain of tobacco budworm.

Reassigned to the Subtropical Agricultural Research Laboratory, Biological Control of Insects Research Unit, to study lethal and sublethal effect of pesticides on beneficial insects.

FY97 & FY98 WORK PLANS

INVESTIGATOR'S NAME(S):		H. R. Gross, J. J. Hamm, and J. E. Carpenter
AFFILIATION & LOCATION:		USDA-ARS, IBPMRL, Tifton, GA
ACTION AREA:	5	Biological Control
LEAD ARRAY:	5.1	Develop technology for managing H/H spp. using entomopathogens/nematodes
OPTIM ARRAY:	5.1.2c	Develop application technology for optimum field efficacy
DATES COVERED BY REPORT:		November 1993-May 1997

PROGRESS REPORT: A beehive-mounted device was developed which forced honey bees exiting the hive to pass through a formulation of *Heliothis* nuclear polyhedrosis virus. The surface of the bees became contaminated with the virus formulation which they carried to the flowers of crimson clover which they visited for nectar and/or pollen. The mean percentage of NPV-induced mortality was significantly higher among *Helicoverpa zea* larvae that fed on clover heads collected from fields foraged by NPV-contaminated bees and among *H. zea* larvae collected from those fields than among similarly exposed control larvae. On September 20, 1994, the USDA obtained U.S. Patent No. 5,348,511, on a "Beehive-mounted device for utilizing honeybees (Hymenoptera: Apidae) in the dissemination of biocontrol agents". Although there was a great deal of interest among bee keepers around the world, no one has obtained rights to the patent for production and sale of the device.

FY97 & FY98 WORK PLANS:

INVESTIGATORS'S NAME(S): J. J. Hamm, H. R. Sumner, and L. D. Chandler

AFFILIATION & LOCATION: USDA-ARS, IBPMRL, Tifton, GA

ACTION AREA: 5 Biological Control

LEAD ARRAY: 5.1 Develop technology for managing H/H spp. using entomopathogens/nematodes

OPTIM ARRAY: 5.1.2c Develop application technology for optimum field efficacy

DATES COVERED BY REPORT: November 1993-November 1995

PROGRESS REPORT: The fluorescent brightener, Tinopal LPW, was tested with fall armyworm nuclear polyhedrosis virus (NPV) against fall armyworm in whorl-stage corn. The fluorescent brightener interacted significantly with virus concentration and water volume to increase larval mortality. There was no increase in mortality due to NPV as the percent fluorescent brightener increased beyond 1 percent. In the higher volumes of water, 0.25 percent fluorescent brightener resulted in the percent mortality due to NPV. Laboratory tests indicate that the fluorescent brightener may be useful in a formulation of the celery looper NPV against *H. zea* and *H. virescens*.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		Carlo M. Ignoffo
AFFILIATION & LOCATION:		USDA-ARS, Biological Control of Insects Research Laboratory, 1503 S. Providence, Columbia, MO 65205
ACTION AREA:	5	Biological Control
LEAD ARRAY:	5.1	Develop technology for managing H/H spp. using entomopathogens/nematodes
OPTIM ARRAY:	5.1.2b	Develop formulation technology that will contribute to greatest field efficacy (entomo.): improve persistence to at least 7 days
DATES COVERED BY REPORT:		1993 to 1997 inclusive

PROGRESS REPORT: Carbon protects viral insecticides from sunlight inactivation. Biological insecticides such as viruses, bacteria, and fungi are sensitive to sunlight and must remain viable in the environment in order to exert effective control over insect pests. Sunlight, however, inactivates these biologicals within three days of applications. In laboratory and simulated field tests, formulations of the H/H virus with carbon, exposed to sunlight, were as stable as the same formulation not exposed to sunlight.

Stable dust formulations of microbial insecticides. Sunlight completely inactivates microbials 1 to 3 days after they are used. Dusts, however, could enhance field persistence of microbial insecticides. In laboratory tests, experimental dust formulations of the H/H virus, talc, and a UV-protectant exposed to sunlight were as stable as the same formulation not exposed to sunlight. The results suggest that dusts may be an untapped potential for formulation of baculoviruses and possibly other microbial insecticides.

FY 98 & 99 WORK PLANS: Continue with studies to develop formulation and technologies for microbial insecticides to be used against larvae of the H/H complex.

INVESTIGATOR'S NAME(S):		Arthur H. McIntosh
AFFILIATION & LOCATION:		USDA-ARS Biological Control of Insects Research Laboratory, Columbia, MO
ACTION AREA	5	Biological Control
LEAD ARRAY	5.1	Develop technology for managing H/H spp. using entomopathogens/nematodes
OPTIM ARRAY	5.1.2a	Improve efficacy through natural or genetic manipulation of entomopathogens
SAFEGD ARRAY	5.2.1b	Identify and characterize strains/species of native and introduced natural enemies of H/H
DATES COVERED BY REPORT:		1993-1996

PROGRESS REPORT: A total of eight cell lines were established from the major pests *Helicoverpa armigera (3)* and *H. punctigera* (5) from ovaries and embryos. Cell lines were heterogeneous in nature and ranged in morphology from oval to fibroblastic-like. Cell lines of both species supported the replication of HzSNPV and AcMNPV. The highest titer (1×10^5 $TCID_{50}$/ml) of HzSNPV was obtained in an *H. armigera* (HA2) cell line but was four fold less than observed in an *H. zea* cell line (HZ-AM1) that is routinely used for production of this baculovirus. On the other hand AcMNPV replicated to the highest titer (4×10^7 $TCID_{50}$/ml) in an *H. punctigera* cell line (HP5) and four fold higher than control *Heliothis virescens* cells (HV-AM1). (Years 3-5).

Two *H. zea* cell lines (HZ-AM1and HZ-1B3) were successfully grown in a formulated and commercial serum-free medium (SFM) and used to replicate HzSNPV. Titers and occlusion bodies in both SFM and serum containing medium were similar with the exception of the formulated SFM which produced less virus. However, OB produced in cell lines grown in this SFM was equally infectious for *H. zea* larvae as OB derived from cell lines in other media. The highest titer observed in SFM was 6.0×10^5 PFU/ml. AcMNPV was also evaluated in two cell lines TN-CL1 (*Trichoplusia ni*) and PX2 (*Plutella xylostella*) grown in two commercial SFM. The highest viral titer of 12×10^6 PFU/ml and OB production (10×10^6/ml) was observed in PX2. OB were infectious for *T. ni* larvae. (Years 3 & 4).

A new baculovirus (PxMNPV) isolate with a wide host spectrum has been shown to be highly infectious to *P. xylostella* (diamondback moth) and the tobacco budworm, *H. virescens*, with LC_{50s} of 5.5 and 6.4 OB/cm^2 respectively. The isolate was also infectious for *H. zea* (LC_{50} =37 OB/cm^2), *Spodoptera exigua* (LC_{50} = 70 OB/cm^2), and *T. ni* (LC_{50} = 7 OB/cm^2). PxMNPV is related to but different from AcMNPV. The isolate can be replicated in a number of lepidopteran cell lines. USDA has filed a patent application for this baculovirus. (Years 3-5).

DNA amplification fingerprinting (DAF), a PCR based technique has been successfully used for the first time to characterize and identify 20 insect cell lines derived from 4 orders. (Years 4 & 5).

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAMES(S): P. V. Vail

AFFILIATION & LOCATION: USDA-ARS, HCRL, Fresno, CA

ACTION AREA: 5 Biological Control

LEAD ARRAY: 5.1 Develop technology for managing H/H spp. using entomopathogens/nematodes

DATES COVERED BY REPORT: 1993-1997

PROGRESS REPORT: Fluorescent brighteners have been shown by other researchers to enhance activity of nuclear polyhedrosis viruses by as much as 1,600 fold and also extend the field life. Laboratory and field studies were conducted to determine the possible use of fluorescent brighteners to either enhance viral activity or extend field life of the nuclear polyhedrosis virus (AfMNPV) isolated from *Anagrapha falcifera*. This virus has previously been shown to infect *Trichoplusia ni, Helicoverpa zea, Heliothis virescens, Pectinophora gossypiella, Spodoptera exigua,* and other cotton pests. Early field studies with fluorescent brighteners indicated an extension of 50 percent loss of original activity from 5.5 to 11.5 d on cotton foliage, but only at relatively high virus application rates. In these studies the action of the brightener appeared to be mainly that of a protectant. With the exception of the pink bollworm, we conducted studies to determine the levels of enhancement that might be provided when Af*M*NPV was fed simultaneously with fluorescent brighteners to the above species. These studies showed that enhancement for *T. ni, H. virescens, H. zea,* and *S. exigua* varied from 2.9-13.6 fold for LC_{50} values and 3.7 to 16 fold for LC_{95}. The greatest enhancement occurred with *T. ni*. LT_{50} values were reduced up to 2.1 fold. These studies also showed that several species did not prefer fluorescent brightener-treated diet when given a choice.

Thus far these studies have shown that fluorescent brightners will enhance viral activity in the laboratory. Field tests on cotton, however, have not shown high levels of enhancement. In our studies, fluorescent brightener activity in the field appears to be mainly as a protectant. The lack of preference for fluorescent brighteners must also be considered if these compounds are to be used as adjuvants for viral microbial control agents.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		A. K. Raina
AFFILIATION & LOCATION:		USDA-ARS, BA, IBL, Beltsville, MD
ACTION AREA:	5	Biological Control
LEAD ARRAY:	5.1	Develop technology for managing H/H spp. using entomopathogens/nematodes
OPTIM ARRAY:	5.1.2a	Improve efficiency through natural or genetic manipulation of entomopathogens
DATES COVERED BY REPORT:		November 1993 - May 1997

PROGRESS REPORT: A number of peptide hormones isolated from the nervous system of *Helicoverpa zea* and *Manduca sexta* were screened for adverse effects on the physiology of *H. zea* larvae. When injected into newly molted 5th instar larvae, one of the peptides (HK-II) caused significant weight loss due to lack of feeding and excessive water loss. However, the effect lasted for only 4-6 h, perhaps due to the break down of the peptide. A synthetic gene for HK-II was designed and cloned into a baculovirus expression vector. The recombinant baculovirus was plaque purified and propagated in SF-9 insect cells. When newly hatched *H. zea* larvae were fed for 48 hours diet smeared with the recombinant virus and then transferred to individual diet cups, most of the larvae either died or did not feed or grow beyond 2nd instar. No such effect was noticed with the wild type virus. A patent is being filed for the recombinant virus as a biocontrol agent. Two companies, American Cyanamid and DuPont have requested the recombinant virus under Material Transfer Agreement.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		W. J. Lewis and J. H. Tumlinson
AFFILIATION & LOCATION:		USDA-ARS, IBPMRL, Tifton, GA USDA-ARS, CMAVE, Gainesville, FL
ACTION AREA:	5	Biological Control
LEAD ARRAY:	5.1	Develop technology for managing H/H spp. using entomopathogens/nematodes
	5.2	Develop technology for managing H/H spp. using parasites/predators
DATES COVERED BY REPORT:		August 1993-June 1997

PROGRESS REPORT: The understanding of multitrophic level interactions of parasitoids, entomopathogens, plants, and H/H technology for crop ecosystem management was advanced along several lines: 1) significantly advanced the understanding of how salivary secretions from H/H larvae feeding on plants trigger the plant to emit chemical signals vital to the host searching behavior of parasitoids; 2) demonstrated a corresponding cotton plant response to the H/H feeding resulting in the systemic production of chemicals that slow the feeding and rate of development of the herbivore; 3) demonstrated that these induced parasitoid foraging signals and herbivore arrestment responses of the cotton plant are significantly affected by fertility and water stress levels, thereby opening the prospects of designing management schemes which optimize the expression of these important defense strengths, and prospects for using these responses for monitoring the health of a cotton crop's defensive system; 4) further demonstrated the important role of adult food to effective performance of parasitoids and prospective ways for effective provisions of such food resources; 5) in on-farm, field-size studies, demonstrated the value of cover crops and conservation tillage techniques for increasing the abundance and effectiveness of natural enemies together with softer and more flexible pesticide interventions as part of a total sustainable cotton production system; 6) elucidated several indirect disruptions of parasitoid performance and reproduction caused by systemic pesticides; 7) demonstrated ability of H/H larvae to behaviorally select clean versus *Bt* treated plant material and the prospects of circumventing this behavioral ability.

FY98 & FY99 WORK PLANS: Continue research along the lines indicated in the progress report (above) to develop an ecologically based pest management system for H/H in the southeastern U. S. This management system will be based on three major components: Habitat Management, Development of Crop Attributes, and Use of Biopesticides and Other Therapeutic Measures with Minimum Interference.

INVESTIGATOR'S NAME(S):		J. E. Carpenter, P. Greany, and S. M. Ferkovich
AFFILIATION & LOCATION:		USDA-ARS, IBPMRL, Tifton, GA USDA-ARS, CMAVE, Gainesville, FL
ACTION AREA:	5	Biological Control
LEAD ARRAY:	5.2	Develop technology for managing H/H using parasites/predators
SAFEGD ARRAY:	5.2.1a	Develop stable efficacious methods for mass production and quality control and release methods for parasites/predators
SUPPLY ARRAY:	5.2.3b	In vitro rearing of parasites and predators
DATES COVERED BY REPORT:		November 1993-May 1997

PROGRESS REPORT: An artificial diet devoid of any insect host components and a diet presentation method were developed for rearing pupal ectoparasitoids of *Heliothis* and *Spodoptera* spp. Diet reared wasps demonstrated a propensity to search for and parasitize natural hosts in a field cage trial. Longevity of the diet reared wasps was comparable with the longevity of wasps reared on host pupae. Survival rate of diet reared wasps was 67.3 percent when reared on died and 76.3 percent when reared on host pupae. Developmental time was significantly longer for wasps reared on the artificial diet than for wasps reared on host pupae. Reduced fecundity and reduced wasp weight were characteristics of diet reared wasps.

In an effort to optimize this diet, we are investigating the potential of providing requisite host factors or their products for parasitoids or predators through the use of insect cell lines and/or their products. Preliminary results indicate that the average weight of parasitoids grown on the cell line-supplemented diet was significantly greater that the weight of parasitoids grown on the control diet, and was comparable to the weight of parasitoids reared on the natural host. The rate of development, cocoon production, and adult emergence of parasitoids reared on the supplemental diet were similar to that of parasitoids reared on the control diet. Although the data presented here were obtained from *Diapetimorpha introita*, a parasitoid of *Spodoptera* spp., this diet also has been used successfully to rear *Cryptus albitarsus*, a parasitoid of *Heliothis virescens*.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		F. I. Proshold, H. R. Gross, and J. E. Carpenter
AFFILIATION & LOCATION:		USDA-ARS, IBPMRL, Tifton, GA
ACTION AREA:	5	Biological Control
LEAD ARRAY:	5.2	Develop technology for managing H/H using parasites/predators
SAFEGD ARRAY:	5.2.1a	Develop stable efficacious methods for mass production and quality control and release methods for parasites/predators
SUPPL ARRAY:	5.2.3b	In vitro rearing of parasites and predators
DATES COVERED BY REPORT:		November 1993-May 1997

PROGRESS REPORT: A three year pilot test was conducted to determine the feasibility of controlling early season populations of corn earworm, *Helicoverpa zea* (Boddie), and fall armyworm, *Spodoptera frugiperda* (J. E. Smith), by augmentative releases of the tachinid parasitoid *Archytas marmoratus* (Townsend). Percentage parasitism of corn earworm larvae was increased to 42 percent in non-isolated fields of whorl-stage corn and > 90 percent in isolated fields by inundative releases (=1500 per ha per week). Fall armyworm larvae were parasitized at a much lower rate than corn earworm larvae. In a contiguous corn growing area, there was a positive correlation between density of corn earworm larvae and percentage parasitism within 0.8 km of the release field. The field with the greatest larval density and percentage parasitism of corn earworm larvae was the one farthest from the release site, indicating good host fining capability by *A. marmoratus*. These results show that inundative releases of this parasitoid could become an important component of integrated management strategies against early season populations of corn earworms and fall armyworms. The high percentage of superparasitism in corn earworm larvae suggests that the release rate of *A. marmoratus* will need to be adjusted to host larval density.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		J. E. Carpenter, S. D. Pair, and T. J. Kring
AFFILIATION & LOCATION:		USDA-ARS, IBPMRL, Tifton, GA USDA-ARS, SCARL, Lane, OK Univ. of Arkansas, Fayetteville, AR
ACTION AREA:	5	Biological Control
LEAD ARRAY:	5.2	Develop technology for managing H/H spp. using parasites/predators
SAFEGD ARRAY:	5.2.1a	Develop stable efficacious method for mass production and quality control and release methods for parasites/predators
SUPPL ARRAY:	5.2.3b	In vitro rearing of parasites and predators
DATES COVERED BY REPORT:		November 1993-May 1997

PROGRESS REPORT: *Ichneumon (=Pterocormus) promissorius* (Erichson) (Hymenoptera: Ichneumomidae) is native to Australia where it has been collected from *Helicoverpa* spp. This pupal parasitoid searches the soil surface for host pupation sites, burrows into the pupal gallery, and oviposits into the host pupa. *I. promissorius* was reared on corn earworm pupae in the laboratory and released in locations in Georgia, Arkansas, Texas, and Oklahoma. Data from this study indicated that these parasitoids were successful in locating and parasitizing indigenous corn earworm pupae in most of the release locations. *I. promissorius* also parasitized some fall armyworm pupae in Georgia and Texas. Several factors were found to influence the longevity and fecundity of *I. promissorius* including mating status, the frequency in which females were exposed to hosts, the hosts from which females developed, and host size.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S): J. J. Hamm and W. J. Lewis

AFFILIATION & LOCATION: USDA-ARS, IBPMRL, Tifton, GA

ACTION ARRAY: 5 Biological Control

LEAD ARRAY: 5.2 Develop technology for managing H/H spp. using parasites/predators

DATES COVERED BY REPORT: November 1996 - May 1997

PROGRESS REPORT: Discovered a nonoccluded baculovirus infecting *Cotesia marginiventris*. This virus is similar to and possibly the same as the nonoccluded baculovirus which infects *Microplitis croceipes* causing reduced emergence of adults and early mortality of adults.

Determined the ascovirus isolates from *H. zea, H. virescens,* and *Trichoplusia ni* can interfere with development of *Microplitis croceipes* and *Cardiochiles nigriceps* in ascovirus-infected larvae. Ascovirus did not interfere with development of the tachinid parasitoid *Eucelatoria rubentis* in *H. zea* larvae infected with the ascovirus isolate from *H. virescens*.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		Guillermo A. Logarzo
AFFILIATION & LOCATION:		USDA-ARS, Southern American Biological Control Laboratory, Bolivar 1559, Hurlingham (1686), Buenos Aires, Argentina
ACTION AREA:	5	Biological Control
LEAD ARRAY:	5.2	Develop technology for managing *H/H* spp. using parasites/predators
DATES COVERED BY REPORT:		1995-1996

PROGRESS REPORT: South American parasitoids can biocontrol North American species of bollworm. More than 30 species of parasitoids have been imported into the U. S. from different parts of the world for biocontrol, however none of them came from South America. In December 1994, the ARS Laboratory in Argentina, in cooperation with the University of Santiago Del Estero, started to search for parasitoids of the South American species of this complex. So far, we have obtained information about the species of the complex occurring in Argentina, their phenology, target crops, and parasitoids present. Eight species of parasitoids have been found, with some of them being potential biocontrol agents. In the future our goal is to address collection efforts towards an increase on the diversity and quantity of parasitoids. Also, more collection sites, like Bolivia and Paraguay, will be included.

1995 - *H. virescens*, the most important species that attacks cotton in the U. S. is seldom found in Argentina. The most important cotton pest in Argentina is *Helicoverpa gelotopoeon*, a species that is restricted to South America. *H. virescens* is cited on tobacco in Argentina, but it was not found in any of the surveyed tobacco crops in the west side of the country. *Heliothis tergiminus* was collected on tobacco. During 1995, 1,186 larvae were collected: 677 *H. gelotopoeon* (57.1 percent) on cotton, and 509 *H. tergiminus* (42.9 percent) on tobacco. Four species of parasitoids (*n*=36) were found on *H. gelotopoeon: Archytas incertus* (Tachinidae) (27); *Campoletis curvicauda* (Ichneumonidae) (6); *Lepestia grioti* (Tachinidae) (2); and *Ophion flavidus* (Ichneumonidae) (1). Four species of parasitoids (*n*=58) were found on *H. tergiminus: Campoletis* sp., Ichneumonidae, (50); *Eucelatoria eucelatoroides*, Tachinidae (2); *Aleioides nigriceps*, Brachonidae, (1); and *Conura* sp., Chalcididae, (1). The density of larvae of *H. gelotopoen* was 2.4 larvae per plant. Colonies of *H. gelotopoeon* and of *H. tergiminus* were successfully established at the lab. Attempts to establish a colony of *Campoletis* sp. at the lab failed.

1996 - During this season, 2,220 larvae were collected: 1,868 *H. tergiminus* (84.9 percent) on tobacco; 272 *H. gelotopoeon* (12.4 percent) on cotton; 59 *H. zea* (2.7 percent) on corn; and 21 *H. virescens* (1 percent) on tobacco. This was the first collection of *H. virescens* made on this crop (east of the country). From the collected larvae, a total of 298 parasitoids were emerged: 88 specimens of *Campoletis* sp. (Ichneumonidae) and 9 *Eucelatoria eucelatoroides* (Tachinidae) from *H. tergiminus*; 32 specimens of *Campoletis* sp., 11 *Campoletis curvicauda* and 6 *Archytas incertus* (Tachinidae) from *H. gelotopoeon*. No parasitoids were obtained from *H. zea*. The density of the larvae of *H. gelotopoeon* showed a pronounced reduction in the number of larvae per plant (2.4 larvae per plants in 1994-95 to 0.5 in 1995-96).

Oviposition preference of *H. tergiminus* on tobacco crops was studies, 78.1 percent of the eggs were deposited on the back of the leaves, 81.8 percent of the eggs were deposited between the 3rd and 7th leaf (*n*=165). The average number of eggs per plant was 3.9 (SD=2.9, n=46). No parasitoids emerged from eggs of *H. tergiminus*.

A colony of *H. virescens* was established at the lab apart from the colonies of *H. tergiminus* and *H. gelotopoeon*. A colony of *Campoletis* sp. was initiated from *H. tergiminus*. Three generations were obtained from each colony with an efficiency of 59, 9, 10, and 21.7 percent respectively. Three shipments, totaling 164 specimens (pupae and adults), of *Campoletis* sp. from *H. tergiminus* were sent to Stoneville - two were sent in December 1995 and the last in May 1996,

FY97 & FY98 WORK PLANS: Right now Guillermo Logarzo is getting his MS degree at NMSU and the project is interrupted until December 1998. The next steps to be followed are:

Increase collecting efforts on *H. zea*

I. Expand the area of exploration in order to include Paraguay and Bolivia

II. Establish a 1-3 ha cotton crop trap in Santiago Del Estero, artificially infested with *H. gelotopoeon*, to attract parasitoids.

INVESTIGATOR'S NAME(S): A. K. Raina

AFFILIATION & LOCATION: USDA-ARS, BA, IBL, Beltsville, MD

ACTION AREA: 5 Biological Control

LEAD ARRAY: 5.3 Develop an IPM program emphasizing use of biocontrol practices and natural enemies as part of integrated systems

DATES COVERED BY REPORT: November 1993 - May 1997

PROGRESS REPORT: In a laboratory colony of *Helicoverpa zea* from Stoneville, MS, we found about 30 percent of the adults with severely atrophied reproductive organs. This agonadal condition was found to be caused by a novel virus named *H. zea* reproductive virus (*Hz*RV). The virus appears to be highly specific to *H. zea*. Atypical occlusion bodies containing large concentrations of virions embedded in a granular matrix were seen in the lumen of highly deformed oviduct and bursa copulatrix of infected females. The virus, transmitted through both eggs and sperm, was successfully propagated in vivo and in tissue culture. *Hz*RV genome is about 225 kbps in size with no similarity to the *Ac*MNPV genomic DNA as determined by Southern hybridization. *Hz*RV at 1/100 female equivalents, injected into a newly emerged female that was mated to a normal male resulted in > 95 percent agonadal progeny. However, at lower doses of the virus, some of the progeny look normal but apparently carry a low level of the virus that could be responsible for sustenance of infection in a given colony as well as in nature. Two other methods of disseminating the virus are being studied. A PCR based assay has been developed to detect the virus even in a single infected egg.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S): Carlo M. Ignoffo

AFFILIATION & LOCATION: USDA-ARS, BCIRL, Columbia, MO

ACTION AREA: 5 Biological Control

LEAD ARRAY: 5.3.1 Field assessment and fate of artificially applied/released entomopathogens and parasites/predators

DATES COVERED BY REPORT: 1993 - 1997 inclusive

PROGRESS REPORT: Environmental persistence of recombinant viruses. Genetically engineered, recombinant viruses are being developed to increase the field effectiveness of these safe microbial insecticides. Our research demonstrated that there was 1 ¼ to 2 ½ times more virus produced in wild-type infected larvae than in larvae infected with a recombinant virus. Because more recombinant infected-larvae than wild-virus infected larvae are expected to fall intact to the ground and lyse this could result in a more rapid environmental buildup of recombinant virus in the soil.

FY97 & FY98 WORK PLANS: Continue studies to assess environmental impact on entomopathogens that are potential candidates for use as microbial insecticides.

INVESTIGATOR'S NAME(S):		H. R. Gross, C. E. Rogers and J. E. Carpenter
AFFILIATION & LOCATION:		USDA-ARS, IBPMRL, Tifton, GA
ACTION AREA:	5	Biological Control
LEAD ARRAY:	5.3	Develop an IPM program emphasizing use of biocontrol practices and preservation of natural enemies in decision-making as part of integrated systems
OPTIMUM ARRAY:	5.3.2	Improve rearing methods for host material for pathogens and for parasites/predators
SUPPL ARRAY:	5.3.3	Protection of successive crops by early application of entomopathogens and beneficial arthropods
DATES COVERED BY REPORT:		November 1993 - May 1997

PROGRESS REPORT: Four standard diets developed by Balazs (1958), Beck (1960), Dutkey et al. (1962), and King et al. (1979) commonly used to rear the greater wax moth, *Galleria mellonella* (L.), were evaluated for their effects on the development of a harbored tachinid parasitoid, *Archytas marmoratus* (Townsend). Incorporating up to 2 ml of Poly Vi Sol vitamin mix and up to 30 g of granular sucrose into a standard laboratory diet (ca.165 g) had no significant influence on the weight of *G. mellonella* larvae nor on the development of *A. marmoratus*. However, as little as 5 g of torula yeast, honey comb wax, or wheat germ added to the King et al. (1979) diet or to varying ratios of Gerber's Mixed and Hi-Protein cereals increased the weight of mature *G. mellonella* larvae and subsequently male and female *A. marmoratus* reared from *G. mellonella* hosts. The King et al. (1979) diet supplemented with torula yeast, honeycomb wax, and wheat germ may be used for mass propagation of *A. marmoratus* until a sufficient artificial diet for its in vitro rearing is developed.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		Glynn Tillman
AFFILIATION & LOCATION:		USDA-ARS, BCMRRU, Starkville, MS
ACTION AREA:	5	Biological Control
LEAD ARRAY:	5.3	Develop an IPM program emphasizing use of biocontrol practices and preservation of natural enemies in decision making as part of integrated systems
DATES COVERED BY REPORT:		November 1993-Present

PROGRESS REPORT: Susceptibility of three parasitoids, *Cardiochiles nigriceps, Cotesia marginiventris,* and *Microplitis croceipes*, to field rates of various insecticides used in control of pests in cotton was determined using a spray chamber. The 14 insecticides used for comparisons between *C. nigriceps* and *M. croceipes* were acephate, azinphosmethyl, bifenthrin, chlorpyrifos, dicrotophos, dimethoate, cyfluthrin, cyhalothrin, cypermethrin, endosulfan, methyl parathion, axamyl, profenofos, and thiodicarb. All of these insecticides, except for thiodicarb, were extremely toxic to *M. croceipes*. Treatment with the five insecticides, thiodicarb, acephate, oxamyl, azinphosmethyl and cypermethrin, resulted in higher survival for *C. nigriceps* adults than treatment with the other nine insecticides. Cypermethrin was less toxic to *C. nigriceps* females that the other three pyrethroids tested. The 14 insecticides used for the studies on *C. marginiventris* included: acephate, azinphosmethyl, bifenthrin, cyhalothrin, cypermethrin, endosulfan, esfenvalerate, fipronil, methomyl, methyl parathion, oxamyl, profenofos, thiodicarb, and Pirate. Eleven of these fourteen insecticides were extremely toxic to *C. marginiventris*, causing 92-100 percent mortality of adult wasps, whereas treatment with thiodicarb, oxamyl, and acephate resulted in lower mortality of *C. marginiventris* males and females. For both male and female *C. marginiventris*, thiodicarb and oxamyl were less toxic than acephate. Esfenvalerate was the least toxic pyrethroid for *C. marginiventris* females.

The tolerance of four natural enemies, *Coccinella septempunctata, Geocoris punctipes, C. marginiventris*, and *C. nigriceps* to the insecticides, malathion, fipronil, and cyfluthrin, directly applied ultra low volume (ULV) on the insects was determined using a spray chamber. All of the insecticides resulted in 100 percent mortality 48 h after treatment for each natural enemy.

The tolerance of two natural enemies, *G. punctipes* and *C. nigriceps*, to residues to malathion, fipronil, and cyfluthrin applied ultra low volume (ULV) was determined. Cotton leaves were picked from field plots 0, 24, and 48 HAT (hours after treatment). Exposure to malathion residues at 0 HAT resulted in highest mortality for both insects. Cyfluthrin was less toxic than malathion at 0 HAT for both insects. Toxicity of malation residues decreased sharply at 48 HAT for both insect species. Toxicity of fipronil was lower of the two natural enemies at 24 HAT compared to 0 HAT. Also, fipronil was less toxic to *C. nigriceps* than to geocorisat 24 HAT. Incidence of parasitism of tobacco budworm larvae associated with tobacco nurseries in cotton plots was determined in 1996 at Mississippi State, MS. Percentage parasitism by *C. nigriceps* was highest in the tobacco nurseries, 47.9 percent, and similar in cotton plots with a nursery, 20 percent, and cotton plots without a nursery, 28.6 percent. These preliminary results indicate that the tobacco nurseries provided a protective habitat for this natural enemy to increase in the field.

Sesame nurseries were established in cotton plots in 1996 at Mississippi State, MS, for natural enemies. During peak population density of *H. virescens*, the mean number of larvae/plant was 3.54 and 0.5 for sesame nurseries and cotton, respectively. At this time, incidence of parasitism of tobacco budworm larvae by *C. nigriceps* was 53.3 percent in sesame nurseries and 3.5 percent in cotton. These preliminary results indicate that the sesame nurseries were a trap crop for the tobacco budworm, and they also provided a protective habitat for the population of the parasitoid to increase.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		J. J. Hamm and J. E. Carpenter
AFFILIATION & LOCATION:		USDA-ARS, IBPMRL, Tifton, GA
ACTION AREA:	5	Biological Control
LEAD ARRAY:	5.3	Development of IPM programs emphasizing use of biocontrol practices and preservation of natural enemies in decision-making as part of integrated systems
OPTIMUM ARRAY:	5.3.2	Improve rearing methods for host material for pathogens and for parasites/predators
SUPPL ARRAY:	5.3.3	Protection of successive crops by early application of entomopathogens and beneficial arthropods
DATES COVERED BY REPORT:		November 1993-May 1997

PROGRESS REPORT: Confirmed that the agonadal condition in was caused by a virus (GSV) and determined that the condition occurred only in moths produced from eggs laid on oviposition days 3 or greater. This suggested a means of eliminating the virus from colonies by saving progeny only from the first two oviposition days. This method of eliminating the disease from colonies of *H. zea* has been documented by researchers at Mississippi State.

Determined that the gonad-specific virus (GSV) does not affect infectivity of the *Heliothis* nuclear polyhedrosis virus (NPV) and thus would not interfere with the use of NPV in the field.

Determined the compatibility of nuclear polyhedrosis viruses and inherited sterility for control of corn earworm and fall armyworm.

FY97 & FY98 WORK PLANS:

Research Summary

Action Area V. Biological Control

Compiled by: D. A. Streett & P. G. Tillman

The H/H National Suppression Action Plan identified three major areas for research in biological control: 1) Develop technology for managing H/H spp. using entomopatogens/nematodes; 2) Develop technology for managing H/H spp. using parasites/predators; 3) Develop an IPM program emphasizing use of biocontrol practices and preservation of natural enemies in decision-making as part of integrated systems.

LEAD ARRAY: 5.1: Significant progress has been made toward developing application technology for optimum field efficacy of entomopathogens. Fluorescent brighteners have been shown to enhance activity and extend field persistence of nuclear polyhedrosis viruses. High virus application rates with fluorescent brighteners have been shown to extend the 50 percent loss of original activity from 5.5 to 11.5 d on cotton foliage. Fluorescent brighteners have also been shown to interact significantly with the fall armyworm NPV to increase larval mortality. However, no increase in larval mortality due to a virus has been observed at fluorescent brightener concentrations beyond 1 percent.

Considerable progress has been made in formulation technology to improve entomopathogen field efficacy and persistence. *Heliothis* virus formulations with carbon, when exposed to sunlight, were as stable as the same formulation not exposed to sunlight. Dust formulations of microbial insecticides were also found to enhance field persistence.

Significant progress has been made in evaluating genetically-modified insect viruses and identifying substances to enhance the activity of wild-type viruses. A genetically-modified virus has been found to kill larvae 25 percent faster than the wild strain of the virus. A survey of substances to enhance the activity of insect viruses has found scorpion venom (*Leiurus*) to be 100X more toxic to *H. zea* than the insect toxin from *Androctonus.* Venom have also been identified from Eulophid species that differ in host range. A purified component from the venom of *E. comstockii* was able to arrest the larval-larval ecdysis process in *Trichoplusia ni.* A recombinant virus containing a gene coding for a peptide hormone (HK-II) caused neonate *H. zea* larvae to either die or cease growing beyond the 2nd instar.

Considerable progress has been made in the selection/identification of specific entomopathogens with the potential for greater efficacy and in the technology required for production of both natural and genetically-modified entomopathogens. A total of eight cell lines have been established from *Helicoverpa* spp. Two *H. zea* cell lines have been successfully grown in a commercial serum-free medium and used to replicate HzSNPV. Application of HzNPV in management programs to suppress the tobacco budworm and bollworm populations during the first larval generation has resulted in a reduction in adult numbers in later generations.

Some progress has been made in developing application technology for entomopathogens. A beehive-mounted device was developed to promote dispersal of the *Heliothis* virus to flowers of the crimson clover.

No progress has been made toward standardization of bioassays of entomopathogens.

LEAD ARRAY: 5.2: Considerable progress has been made in improving the efficiency and persistence of parasitoids through chemical and behavioral ecology of parasitoids. Significantly advanced the understanding of how salivary secretions from H/H larvae feeding on plants trigger the plant to emit chemical signals vital to the host searching behavior of parasitoids. Demonstrated a corresponding cotton plant response to the H/H feeding resulting in the systemic production of chemicals that slow feeding and rate of development of the pest. Demonstrated that foraging signals and pest arrestment responses of the plant are affected by fertility and water stress levels. Demonstrated the importance of adult food to effective performance of parasitoids. Demonstrated the value of cover crops and conservation tillage techniques for increasing the abundance and effectiveness of natural enemies. Elucidated several indirect disruptions of parasitoid performance and reproduction caused by systemic pesticides.

Demonstrated ability of H/H larvae to select clean versus *Bt* treated plant material. Discovered a nonoccluded baculovirus infecting *Cotesia marginiventris*.

A lot of progress has been made in surveying parasitoids H/H species in Argentina. During 1995, *Archytas incertus*, *Campoletis curvicauda*, *Lepestia grioti*, and *Ophion flavidus* were found from *H. gelotopoeon* on cotton. *Campoletis* spp., *Eucelatoria eucelatoroides*, *Aleioides nigriceps*, and *Conura* spp. were found on *H. tergiminus* on tobacco. In 1996, *Campoletis* spp. and Eucelatoria eucelatoroides were collected from *H. tergiminus*, and *Campoletis* spp., *Campoletis curvicauda*, and *Archytas incertus* were collected from *H. gelotopoeon*.

Considerable progress has been made toward field evaluation of native and imported species of parasitoids. A 3-yr pilot test demonstrated the feasibility of controlling early season populations of the corn earworm by augmentative releases of *Archytas marmoratus*. Percentage parasitism of corn earworm larvae was increased to 42 percent in non-isolated fields of whorl-stage corn and > 90 percent in isolated fields by inundative releases. A positive correlation between density of corn earworm larvae and percentage parasitism was demonstrated. Results from field releases of *Ichneumon promissorius* in Georgia, Arkansas, Texas, and Oklahoma indicate that this parasitoid was successful in locating and parasitizing indigenous corn earworm pupae in most of the release locations.

Some progress has been made toward developing quality control in mass production of parasitoids. Demonstrated propensity of pupal parasitoids reared on artificial diet to search for and parasitize natural hosts in a field cage trial. Longevity of diet reared wasps was similar to that of wasps reared on host pupae. Developmental time was longer for wasps reared on diet than that for wasps on pupae. Reduced fecundity and wasp weight were characteristic of diet reared wasps. Preliminary results indicate that the weight of parasitoids grown on a cell line-supplemented diet was comparable to the weight of parasitoids reared on the host.

LEAD ARRAY 5.3: Significant progress has been made in rearing host larvae for *Archytas marmoratus*. The King et al. (1979) worm diet supplemented with torula yeast, honeycomb wax, and wheat germ may be used for rearing *Galleria mellonella* for mass propagation of *A. marmoratus*. Adult *H. zea* were found with severely atrophied reproductive organs and this condition was caused by a novel virus named the *H. zea* reproductive virus (*Hz*RV). This agonadal condition occurred in moths produced from eggs laid in oviposition day 3 or greater.

Considerable progress has been made toward determining direct effects of insecticides on natural enemies. Malathion, fipronil, and cyfluthrin directly applied ultra low volume (ULV) on the insects resulted in 100 percent mortality 48 h after treatment for four natural enemies, *Coccinella septempunctata*, *Geocoris punctipes*, *Cotesia marginiventris*, and *Cardiochiles nigriceps*. Tolerance of two natural enemies, *G. punctipes* and *C. nigriceps*, to residues of malathion, fipronil, and cyfluthrin applied ultra low volume (ULV) was determined. Exposure to malathion residues at 0 HAT (hours after treatment) resulted in highest mortality for both insects. Cyfluthrin was less toxic than malathion at 0 HAT for both insects. Toxicity of malathion residues decreased sharply at 48 HAT for both insect species. Toxicity of fipronil was lower for the two natural enemies at 24 HAT compared to 0 HAT. Also, fipronil was less toxic to *C. nigriceps* than to *G. paritipae* at 24 HAT.

Some progress has been made toward demonstrating the value of in-season nurseries for increasing the abundance of natural enemies in the cotton field. Percentage parasitism by *C. nigriceps* was highest in the tobacco nurseries, 47.9 percent, and similar in cotton plots with a nursery, 20.0 percent, and cotton plots without a nursery, 28.6 percent. During peak population density of *Heliothis virescens*, the mean number of larvae/plant was 3.54 and 0.5 for sesame nurseries and cotton, respectively. At this time, incidence of parasitism of tobacco budworm larvae by *C. nigriceps* was 53.3 percent in sesame nurseries and 3.5 percent in cotton. These preliminary results indicate that the nurseries provided a protective habitat for the population of the parasitoid to increase.

Wild-type infected larvae produce 1.25 to 2.5 times more virus than larvae infected with a genetically-modified virus.

Progress Report
Action Area VI. Genetics, Molecular Biology & Basic Physiology

Coordinators: J. E. Carpenter & D. R. Nelson

INVESTIGATOR'S NAME(S):		L. J. Heilmann, C. Krueger, and S. K. Narang
AFFILIATION & LOCATION:		Biosciences Research Laboratory, USDA-ARS, Fargo, ND
ACTION AREA:	6	Genetics, Molecular Biology, and Basic Physiology
LEAD ARRAY:	6.1	Mechanisms of backcross sterility in *Heliothis virescens* and transfer of Backcoll Sterility Check to *Helicoverpa zea*.
DATES COVERED BY REPORT:		1993-1994

PROGRESS REPORT: It has been postulated that endosymbiont bacteria-like organisms are responsible for the male backcross sterility observed when *Heliothis virescens* and *Heliothis subflexa* are crossed. To identify these endosymbionts we used the Polymerase Chain Reaction to amplify 16S ribosomal RNA genes of bacteria present in the sperm of the two species and the backcross males. The amplified gene segment was the same size in *H. subflexa* and the backcross males and about 50 base pairs larger than the same segment from *H. virescens*. This supports the hypothesis that the endosymbionts in backcross males are derived from the female (*H. subflexa*) parent. We cloned and sequenced the 16S ribosomal gene segment from each of the three species. The sequence was analyzed and compared to each other and to the GENBANK database. The backcross and *H. subflexa* sequences were exactly the same size and differed by only seven base changes out of 799. The *H. virescens* sequence differed from the other two considerably. It was 49 bases smaller. All of this could be attributed to three small deletions. Maximum homology between the *H. virescens* sequence and the *H. subflexa* and backcross sequences was 76 percent. Comparisons with the GENBANK database showed that both sets of sequences showed most similarity with the purple bacteria but with different subsets of that family. *H. virescens* endosymbionts were closest in homology to the alpha purple bacteria which include rickettsia such as *Bartonella* sp. and *Wolbachia* sp. The backcross and *H. subflexa* ribosomal sequences placed them in the gamma purple bacteria with closest homology to *Pseudomonas* sp. Identification of the types of bacterial endosymbionts present in species showing backcross male sterility should allow for the isolation of the bacteria and their use to artificially induce sterility in insects.

FY97 & FY98 WORK PLANS:

INVESTIGATORS NAMES(S): J. D. DeVault, K. J. Hughes, R. A. Leopold, and S. K. Narang

AFFILIATION & LOCATION: Biosciences Research Lab, USDA-ARS, Fargo, ND

ACTION AREA: 6 Genetics, Molecular Biology, and Basic Physiology

LEAD ARRAY: 6.2 Evaluate Backcoll Sterility Check as a control concept for *H. virescens* in the Mississippi Delta

DATES COVERED BY REPORT: 1993-1997

PROGRESS REPORT: A DNA delivery method for use in the transfer of plasmid DNA to embryos of Heliothine species was developed for the purpose of effecting germline transformation. The method uses an easily constructed slot cuvette and the electroporation technique instead of the time-consuming individual microinjection of the embryos with DNA plasmids. Reporter genes consisting of a pGEM-3Z vector and also 2 X-glucuronidase constructs (pKrG and pBacPAK8-GUS) were successfully electroporated into *H. zea* embryos. Fifty percent of the embryos hatched and 75 percent survived to adulthood. Using the electroporation technique, the *hobo* transposable element from *Drosophila* was tested for its ability as a gene vector to transpose in a heterologous insect cellular environment. We previously identified *hobo*-like sequences in the genomes of *H. zea* and *H. virescens* which suggested that the *hobo* element may function in these backgrounds. *Trichoplusia ni* and *H. zea* embryonic cell lines were found to be capable of supporting transposition of the *hobo* element as measured by a plasmid-based excision/deletion assay. This assay was also used to detect *hobo* transposition/excision in electroporated embryos of *H. zea*, *H. virescens* and several other lepidopteran species in a manner that was consistent with the results gained with the cell lines. In both the *H. zea* cell line and in the embryos the transposition/ excision events were found to be independent of the vector-encoded tranposase functions, indicating that endogenous genes are involved in *hobo* mobility. Using this system, stable insertion of the bacterial *lacZ* gene into the *H. zea* genome was also accomplished. The inheritance pattern was followed 5 generations and analysis of the corresponding progeny ratios suggested that the *lacZ* sequences are present in a single copy. These results demonstrate that *hobo* elements are capable of transgressing species boundaries and functioning in non-drosophilid insects. More importantly, this represents the first description of a genetic transformation system for a lepidopteran species. Expansion of this technology can allow development of a full repertoire of molecular genetic tools and techniques that currently are not available for solving problems of insect biology that continue to impact world health and agriculture.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S): M.L. Laster (retired)[1], D. D. Hardee[1], J.C.Schneider[2]

AFFILIATION & LOCATION: [1]USDA-ARS-SIMRU, Stoneville, MS 38776
[2]Dept. Of Entomology, Mississippi State University, Mississippi State, MS 39762

ACTION AREA 6 Genetics, Molecular Biology, and Basic Physiology

LEAD ARRAY: 6.2 Evaluate backcross sterility as a control concept for H. virescens in the Mississippi Delta area

DATES COVERED BY REPORT: July 1993 - September 1997

PROGRESS REPORT: A pilot test to suppress a feral tobacco budworm, *Heliothis virescens* (F.), population by rearing and releasing insects with a sterile male trait was conducted during 1991-94 in Washington and Sunflower Counties, Mississippi, and in 1992 and in Bolivar County in 1993. Pheromone traps were used to monitor insect populations in both areas during both years and the non-release area served as the control with moth releases directed at overwintered tobacco budworm emergence. Approximately 69,000 moths per day were released in 1992 and 70,000 per day in 1993. A 3.0:1.0 (released:wild) ratio was achieved in 1992. This ratio dropped to 1.3:1.0 and 1.1:2.3 during June and July, respectively, due to moth movement into and out of the release area. Continued monitoring of this area in 1993 showed a 1.0:2.2 backcross:feral ratio. This ratio dropped to 1.0:5.2 (backcross:wild) in June, increased to 1.0:4.7 and 1.0:3.4 during July and August, respectively. A 2.6:1.0 (released:wild) ratio was achieved for the Bolivar County release in 1993. This ratio declined to 1.0:1.6 in June, 1.0:3.6 in July and 1.0:4.0 in August. Continued monitoring in 1994 showed that male sterility in the overwintered populations across both release areas was 12.1 percent.

FY 98 & FY 99 WORK PLANS: Research on this project has been discontinued.

INVESTIGATOR'S NAME(S): M. L. Laster (retired)

AFFILIATION & LOCATION: USDA-ARS-SIMRU, Stoneville, MS 38776

ACTION AREA 6 Genetics, Molecular Biology, and Basic Physiology

LEAD ARRAY: 6.3 Crossbreeding of *Helicoverpa* spp. to develop backcross sterility in *H. zea*.

DATES COVERED BY REPORT: July 1993 - September 1997

PROGRESS REPORT: *Helicoverpa armigera* (the Old World bollworm) was imported from China into the quarantine research facility at Stoneville, MS, and crossed with *H. zea* (the American bollworm) in search of hybrid sterility. Reciprocal backcrosses through four generations and inbred crosses through two generations were studied to determine mating incidence and fertility. All crosses mated and produced fertile offspring and no sterility was detected.

FY 98 & FY 99 WORK PLANS: Research on this project has been discontinued.

INVESTIGATOR'S NAME(S): J. E. Carpenter, C. M. Mannion, and H. R. Gross

AFFILIATION & LOCATION: USDA-ARS-IBPMRL, Tifton, GA 31793

ACTION AREA: 6 Genetics, Molecular Biology, and Basic Physiology

LEAD ARRAY: 6.4 Potential use of inherited sterility as a control strategy for *H. zea*

SAFEGD ARRAY: 6.4.1 Effects of inherited sterility on *H. zea* physiology, behavior, and reproduction.

DATES COVERED BY REPORT: November 1993- May 1997

PROGRESS REPORT: A pilot test was conducted in small mountain valleys in North Carolina to assess the influence of released, substerilized (100 Gy) males on feral *H. zea* populations, and to measure the infusion rate of inherited sterility into the feral population. Results from this study revealed that the number of feral males captured per hectare was positively correlated with the distance from the release site of irradiated males. Analyses of seasonal population curves of feral *H. zea* males calculated from mark-recapture data suggested that seasonal increases of feral *H. zea* males were delayed and/or reduced in mountain valleys where irradiated males were released. The incidence of larvae with chromosomal aberrations (progeny of irradiated, released *H. zea* males collected from the test sites during the growing seasons) indicated that irradiated males were competitive in mating with feral females and were successful in producing F_1 progeny, which further reduced the feral population.

We found that inherited sterility and augmented natural enemies such as parasitoids and viruses were compatible and complementary control strategies. For example, inundative releases of partially sterile male and female *H. zea* moths could produce large populations of sterile larvae on early-season weeds or possibly whorl-stage corn. The tachinid parasitoid *Archytas marmoratus* (Native or released, or both) could use the sterile larvae as hosts and thereby substantially increase their populations by parasitizing the subsequent generation of *H. zea* larvae. Also, surviving sterile larvae would produce sterile *H. zea* adults that could impact the subsequent generation. Population models indicated that integration of inherited sterility and parasitoids was more efficient than the use of either of these control strategies independently.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S): S. K. Narang, M. E. Degrugillier, J. D. Lopez[1], L. J. Heilmann, J.D. DeVault, D. Hendricks[2], and J. Loera[3]

AFFILIATION & LOCATION: Biosciences Research Laboratory, USDA-ARS, Fargo, ND
[1]USDA-ARS College Station, Texas
[2]USDA-ARS Stoneville, Mississippi
[3]INIFAP, Centro de Investigaciones Agricola, Rio Bravo, Mexico

ACTION AREA: 6 Genetics, Molecular Biology, and Basic Physiology

LEAD ARRAY: 6.5 Establish linkage groups and genetic maps of morphological mutants, allozymes, and DNA sequences

DATES COVERED BY REPORT: 1993-1995

PROGRESS REPORT: There exists considerable circumstantial evidence which supports south to north long range mass spring migration of noctuid pests, however, direct methods to prove their movement from suspected origins in Mexico to the US are lacking. We conducted population genetics studies on *H. zea*. Three populations each from Mexico (Zaragosa, Delicias and Hermosillo) and the US (Corvallis, Ankeny, and Weslaco) were analyzed for mitochondrial DNA restriction differences. The goal was to determine whether some of the differences could be used to distinguish immigrant from resident populations. Of the 58 polymorphic patterns observed, 36 (62 percent) were characteristic of the two regions (present in either Mexico or the US). Some of the remaining 22 (38 percent) patterns showed frequency differences among populations. We illustrated how statistical and probability theory, when applied to low frequency private mtDNA haplotypes alone or to a combination of haplotypes and other markers (allozymes and microsatellites) can be used to identify the geographic source of migrant moths. This migration research is an important component of knowledge on *Helicoverpa* biology and ecology which will serve as a foundation for new discoveries for the development of effective area wide management of this pest complex.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		L. J. Heilmann and S. K. Narang
AFFILIATION & LOCATION:		Biosciences Research Lab, USDA-ARS, Fargo, ND
ACTION AREA:	6	Genetics, Molecular Biology and Basic Physiology
LEAD ARRAY:	6.5	Establish linkage groups and genetic maps of morphological mutants, allozymes, and DNA sequences
DATES COVERED BY REPORT:		1994-1996

PROGRESS REPORT: To distinguish differences in population of some species it is necessary to have markers for genetic differences. We have isolated and characterized a number of microsatellite loci from the cotton bollworm, *Helicoverpa zea,* and used them to demonstrate that a considerable amount of genetic diversity exists among different populations of this pest species. DNA was extracted from a laboratory strain of *H. zea* and a genomic library prepared. This library was screened with 32P labeled oligonucleotides consisting of twelve repeats of the dinucleotide GT. Positive clones were subcloned into plasmids and the portion of the clone containing the microsatellite sequence mapped and purified. The microsatellites and flanking DNA were sequenced. PCR primers were designed from the flanking sequence. These primers were used to amplify the microsatellite containing sequence from the DNA's of individual moths collected from different locations. Amplified sequences were analyzed by agarose gel electrophoresis and staining with ethidium bromide or SYBR Green. Differences in the size of the amplified segment of DNA were scored as polymorphisms. Six different microsatellite sequences were isolated. Two proved useful in PCR analysis. The others consisted of microsatellites embedded in repetitive DNA's that gave complex and unrepeatable patterns. Gel analysis of multiple individuals from two different populations (Florence, SC and Stoneville, MS) showed extensive polymorphism between and within the populations. In analysis of 30 individuals from each population at least 18 different haplotypes were observed (10 from Florence and 8 from Stoneville). The extensive polymorphism indicates that these primers could be used for population analysis but large numbers of individual samples would be needed. The large number of microsatellites of this one dinucleotide sequence indicates that microsatellites will be a valuable and abundant resource of variation for genetic mapping in this species.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S):		J. S. Buckner and D. R. Nelson
AFFILIATION & LOCATION:		Biosciences Research Lab, USDA-ARS, Fargo, ND
ACTION AREA:	6	Genetics, Molecular Biology, and Basic Physiology
LEAD ARRAY:	6.6	Identify the physiological and biochemical basis of insect development, diapause, and reproduction as a component of area wide management
DATES COVERED BY REPORT:		1993- Present

PROGRESS REPORT: *Heliothis virescens* and *Helicoverpa zea* pupae in diapause produce substantially more surface lipid than pupae reared under conditions to promote development. Precursors of lipid synthesis for pupal and adult stages are acquired during the larval feeding stage. Common components of the surface lipids of *H. virescens* and *H. zea* pupae are long-chain hydrocarbons, aldehydes and alcohols, esters of long-chain alcohols with long-chain acids (wax esters), and free fatty acids. Many of these compounds are chemically reactive. It is not known whether these reactive compounds protect the defenseless pupae from soil parasites/predators (fungi, bacteria, insects). Nor is it understood what controls the synthesis of surface lipid in insects "programmed" for diapause (is it hormonal regulation of the biosynthetic mechanisms for lipid synthesis and deposition or perhaps control over the availability of lipid precursors, i.e., acetate available for lipid or alternatively, as a possible energy source for adult development). These Lepidoptera also esterify short-chain acids to long-chain alcohols and deposit the ester on the pupal surface. The number of short-chain acids involved indicate a broad substrate specificity for the acid:alcohol transferase that is likely responsible for the production of the esters. The addition of the short-chain acid, sorbic acid (an anti-fungal agent) to the artificial diet of lab-reared *H. virescens* resulted in the synthesis of two "extra" lipid classes identified as esters comprised of long-chain alcohols esterified to sorbic acid. This phenomenon is somewhat species specific. These findings reveal the existence of novel biochemical systems that appear to be specific to holometabolous insects of agricultural importance: 1) control for the synthesis of pupal surface lipids is related to the process of diapause; 2) short-chain acids are incorporated into ester components of surface lipid by a unique enzyme system which may also be species specific and different from the enzyme that synthesizes wax esters; 3) short-chain acids from artificial diet or plant-fed larvae have potential use as tracers/markers for movement of field-released, lab-reared insects and as host plant feeding identifiers.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S): D. R. Nelson and J. S. Buckner

AFFILIATION & LOCATION: Biosciences Research Lab, USDA-ARS, Fargo, ND

ACTION AREA: 6 Genetics, Molecular Biology, and Basic Physiology

LEAD ARRAY: 6.6 Identify the physiological and biochemical basis of insect development, diapause, and reproduction as a component of area wide management

DATES COVERED BY REPORT: 1994-1995

PROGRESS REPORT: *H. virescens* and *H. zea* can infest the same crop. However, in the larval stage they are difficult or impossible to differentiate. We found that they can be unambiguously identified based on the gas chromatographic profile of the cuticular hydrocarbons. Results can be obtained within 1.5 hours after bringing the larva into the laboratory by directly analyzing a hexane rinse of the larvae. If the gas chromatograph is equipped with a mass spectrometer, the larva can be distinguished in 3 ways: 1) the profile (fingerprint) of the gas chromatographic trace; 2) an alkene, hentriacontene, is a major component of *H. zea* but is not present in *H. virescens;* and 3) the methyl branch positions of the dimethylalkanes differ between the two species.

FY97 & FY98 WORK PLANS:

INVESTIGATOR'S NAME(S): D. R. Nelson and C. L. Fatland

AFFILIATION & LOCATION: Biosciences Research Laboratory, USDA-ARS, Fargo, ND

ACTION AREA: 6 Genetics, Molecular Biology, and Basic Physiology

LEAD ARRAY: 6.6 Identify the physiological and biochemical basis of insect development, diapause, and reproduction as a component of area wide management

DATES COVERED BY REPORT: 1994-1997

PROGRESS REPORT: Very long-chain methyl-branched alcohols and their acetate esters accumulate within pupae during metamorphosis reaching a maximum level about midway through the pupal stage. The maximum rate of synthesis from acetate or propionate is maximal about midway through the pupal stage. The alcohols then decline and are at trace levels at the time of adult eclosion. The function and fate of these novel lipids are unknown. Five homologous series of primary alcohols were identified in all the Lepidoptera studied: *Cochylis hospes* (banded sunflower moth), *Diatraea grandiosella* (southwestern corn borer), *Homoeosoma electellum* (sunflower moth), *Heliothis virescens* (tobacco budworm), and *Helicoverpa zea* (corn earworm): n-alcohols, internally branched monomethyl alcohols, 2 series of dimethyl branched alcohols, and a series of trimethyl branched alcohols. The major components of the 4 methyl-branched series were: 24-methyltetracontanol, 24,28-dimethyltetracontanol, 24,36-dimethyltetracontanol, and 24,28,36-trimethyltetracontanol. Similar methyl-branched alcohols were previously found in *Manduca sexta* (tobacco hornworm) and *Trichoplusia ni* (cabbage looper).

FY97 & FY98 WORK PLANS:

RESEARCH SUMMARY

Action Area VI. Genetics, Molecular Biology & Basic Physiology

Compiled by: J. E. Carpenter & D. R. Nelson

Lead Array 6.1: Mechanisms of backcross sterility in *Heliothis virescens* and transfer of BCS to *Helicoverpa zea*. Sequencing of ribosomal RNA (16S) genes of endosymbiont organisms in sperm of *Heliothis virescens* and *Heliothis subflexa* was used to characterize them and indicated that the endosymbionts in backcross males come from the *H. subflexa* female parent. Nucleotide sequence comparisons indicated the *H. virescens* symbionts has similarities in alpha purple bacteria (*Wolbachia* sp.) and that endosymbionts from *H. subflexa* and backcross males had similarities to gamma purple bacteria (*Pseudomonas* sp.).

Lead Array 6.2: Evaluate BCS as a control concept for *H. virescens* in the Mississippi Delta. Significant progress was made on developing an electroporation method for the transfer of plasmid DNA to embryos of Heliothine species which contain *hobo*-like sequences. The *hobo* transposable element from *Drosophila* was used to insert the bacterial *lacZ* gene into *Helicoverpa zea* genome and was followed for five generations. In both embryos and cell lines the transposition/excision events were independent of vector encoded transposase. A pilot test releasing *H. virescens* with a sterile male train showed that migration of feral moths into the release area caused the released feral ratio to decline to 1:1 and below. A year later, male sterility in overwintered populations was 12 percent. Attempts to create hybrid sterility in *H. zea* by crosses with *Helicoverpa armigera* showed that all crosses mated and all progeny were fertile. Both projects have been discontinued.

Lead Array 6.3: Crossbreeding of *Helicoverpa* spp. to develop BCS in *H. zea*. No progress reported.

Lead Array 6.4: Potential use of inherited sterility as a control strategy for *H. zea*. Considerable progress was made in demonstrating that substerilized *H. zea* males reduced the feral population and also produced F1 progeny. Substerilized males and females produced sterile larvae on early-season weeds and also served as hosts for the tachinid parasitoid *Archytas marmaratus*, all of which would impact subsequent generations of feral *H. zea*.

Lead Array 6.5: Establish linkage groups and genetic maps of morphological mutants, allozymes, and DNA sequences. Analysis of *H. zea* mitochondrial DNA restriction differences was used to illustrate how they could be used alone, or in combination with other markers, to identify geographic sources of migrant moths.

Analysis of *H. zea* microstaellite DNA resulted in two sequences, out of six isolated, which showed that extensive polymorphism existed within and between populations and that using these primers in Polymerase chain reaction analysis would require large numbers of individuals to be analyzed for population analysis.

Lead Array 6.6: Identify the physiological and biochemical basis of insect development, diapause, and reproduction as a component of areawide management. Considerable progress was made in characterizing differences in the surface lipids of larvae of *H. virescens* and *H. zea*. Differences in the gas chromatographic profile of the cuticular surface hydrocarbons enable larvae to be unambiguously identified. A comparison of waxes and of esters of alcohols with short-chain acids showed the *H. virescens* has an enzyme system with broad substrate specificity which incorporates sorbic acid, a common dietary additive, into esters transferred to the cuticle surface. Thus, short-chain dietary acids may provide a means of marking some species for studying field migration. Novel very long-chain methyl-branched alcohols were characterized in pharate adults of Lepidoptera: *Cochylis hospes, Diatraea grandiosella, Homoeosama electellum, Heliothis virescens*, and *Helicoverpa zea*. The alcohols were synthesized from acetate and propionate (source of methyl branches). The fate and function of the alcohols is unknown and they have only been found in olometabolous species.

TECHNOLOGY TRANSFER

NAME OF RESEARCHER(S): R. E. Lynch, B. R. Wiseman, and N. W. Widstrom

AFFILIATION: Plant Resistance/Germplasm Enhancement Research Unit

ACTION AREA: A Host Plant Resistance

SUMMARY: Resistance in corn to the corn earworm identified and germplasm released. Resistance to the corn earworm has been identified in silks of several corn lines. Biochemical research has shown that the resistance is mediated by maysin, apimaysin, chlorogenic acid, and related compounds, with maysin as the most important component. Genetic studies have shown resistance in PI340856 is controlled by a single, dominant gene, while resistance in GT114 is controlled principally by a recessive gene. More recently, SC102 and GE37 were identified as high maysin lines which produce an exceptionally high level of maysin in hybrid combination. This research addresses ARS research priorities for pesticide use/risk reduction, food safety, pest management strategies, and technology transfer.

NAME OF RESEARCHER(S): N. W. Widstrom, R. E. Lynch, and B. R. Wiseman

AFFILIATION: Plant Resistance/Germplasm Enhancement Research Unit

ACTION AREA: A Host Plant Resistance

SUMMARY: CRADA established to transfer resistance to the corn earworm to sweet corn. Currently, it is estimated that 25-40 applications of insecticide are used in the production of sweet corn for the fresh sweet corn market. A CRADA has been established with Rogers Seed Co. to transfer resistance to the corn earworm from high maysin lines to their elite sweet corn inbreds. We estimate that incorporation of the gene(s) for high maysin in corn silks into sweet corn will reduce pesticide usage by 75-85 percent. Transfer will be followed using insect and biochemical bioassays for maysin to identify resistant lines. The initial crosses were made in 1995. The first two cycles of breeding and selection have been completed and testcrosses among resistant elite inbreds will be conducted in 1998 to evaluate the effectiveness of the resistance. It is anticipated that within five years sweet corn germplasm with resistance to this most important insect pest will be commercially available.

NAME OF RESEARCHER(S): N. W. Widstrom

AFFILIATION : Plant Resistance/Germplasm Enhancement Research Unit

ACTION AREA: A Host Plant Resistance

SUMMARY: Aflatoxin model developed and demonstrated. An Aflatoxin prediction model was developed and refined in cooperation with modelers at the National Peanut Research Laboratory, Dawson, GA, and with producers that will assist them in making decisions concerning the risk of Aflatoxin in their corn crop. The Aflatoxin management model was demonstrated at the Georgia Ag Showcase in Tifton, GA, June 29, 1996. The model is used to reduce the probability of Aflatoxin contamination in corn. Preharvest Aflatoxin contamination in corn is associated with drought, high temperatures and insect damage (including corn earworm) to the ear. Use of this model allows producers to make management decisions that will limit Aflatoxin contamination.

NAME OF RESEARCHER(S): R. E. Lynch, B. R. Wiseman, and N. W. Widstrom

AFFILIATION : Plant Resistance/Germplasm Enhancement Research Unit, IBPMRL, Tifton, GA

ACTION AREA: H Host Plant Resistance

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NAME OF RESEARCHER(S): N. W. Widstrom, R. E. Lynch, and B. R. Wiseman

AFFILIATION & LOCATION: Plant Resistance/Germplasm Enhancement Research Unit, IBPRML, Tifton, GA

ACTION AREA: H Host Plant Resistance

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AFFILIATION: Plant Resistance/Germplasm Enhancement Research Unit, IBPMRL, Tifton, GA

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NAME OF RESEARCHER(S): Juan D. Lopez, Jr.

AFFILIATION: USDA-ARS, APMRU, College Station, TX

ACTION AREA:
C Ecology & Population Dynamics
D Behavior Modifying Chemicals

SUMMARY: Plans and specifications were provided to Brazos Valley Sheet Metal Company of Navasota, TX, for the construction of Texas wire cone sex pheromone traps. Trap construction was monitored to assure conformity with plans and specifications. This firm is now a commercial source of the traps. Researchers and crop producers have been ordering traps for use in the monitoring of adult activity levels and to collect samples of both the corn earworm/ bollworm and tobacco budworm for use in vial tests for insecticide resistance and other research.

NAME OF RESEARCHER(S): Juan D. Lopez, Jr.

AFFILIATION: USDA-ARS, APMRU, College Station, TX

ACTION AREA: B Chemical Control & Application Technology

SUMMARY: A CRADA was established with BASF to develop adult control using feeding attractants and stimulants for several species of noctuids including the corn earworm/bollworm and tobacco budworm. A patent claim is being developed to allow for commercial development of this technology. It is expected that this technology will reduce the amount of active ingredient as well as the area tested to control the pests. In addition, this technology has potential for use with other biologically-active materials that are or will be very selective for the target pests.

NAME OF RESEARCHER(S): John K. Westbrook

AFFILIATION: USDA-ARS, APMRU, College Station, TX

ACTION AREA: C Ecology & Population Dynamics

SUMMARY: Commercial atmospheric radiosondes were attached to commercial super-pressure balloons (tetroons) and tracked with a modified (mobile) configuration of a radiosonde receiver. Mean atmospheric pathways of migrating corn earworm moths and other noctuid pests were approximated by the tetroon trajectories. Results from the tetroon trajectories have been established prevailing nocturnal and transport between source and recipient areas. Further, tetroons are being used to detect and collect flying or drifting airborne insects, bats, and other organisms.

NAME OF RESEARCHER(S): S. D. Pair, William Schlotzhauer, and Bob Horvat

AFFILLATION: USDA-ARS, SCARL, Lane, OK, and USDA-ARS, Athens, GA

ACTION AREA: D Behavior-Modifying Chemicals

SUMMARY: Discovery of a new tobacco budworm/bollworm larval host-plant also yields new adult attractants. Japanese honeysuckle was determined as a reproductive host plant of tobacco budworm/bollworm and as potentially contributing to their overwintering and F1 populations in the Southeast. Flowers of Japanese honeysuckle were later found to be attractive to a wide array of economically important adult Lepidoptera; volatile constituents were identified from the flowers and an application was made for a patent for their use in attracticidal baits or in lures for monitoring purposes. This knowledge should be useful for managers considering development of population suppression programs and for private interests seeking alternative biorational compounds for commercialization.

NAME OF RESEARCHER(S): Arthur H. McIntosh

AFFILIATION: USDA-ARS, Biological Control of Insects Research Lab, Columbia, MO 65203

ACTION AREA: E Biological Control

SUMMARY: A new baculovirus isolate for the control of the diamondback moth (DRM) has been shown to be 1,000-2,000 fold (LC-50) more effective than AcMNPV and AfMNPV. The isolate is also effective against members of the Helicoverpa-Heliothis complex as well as Spodoptera exigua (beet armyworm). USDA has filed a patent application for this baculovirus, and a Material Transfer Agreement and CRADA has been established with industry to further develop this product.

NAME OF RESEARCHERS(S): Arthur H. McIntosh

AFFILIATION: USDA-ARS, Biological Control of Insects Research Lab, Columbia, MO 65203

ACTION AREA: E Biological Control

SUMMARY: Cell lines (HzAMI & Hz1b3) derived from Helicoverpa zea were successfully adapted to growth in serum-free media. Such cell lines supported replication of HzSNPV which was infectious for H. zea larvae. This research resulted in a publication (J. Invertebr. Patho. 66:121, 1995). Information from this study will benefit the scientific communities as well as commercial enterprises involved in the in vitro production of balculoviruses.

NAME OF RESEARCHERS(S): Arthur H. McIntosh

AFFILIATION: USDA-ARS, Biological Control of Insects Research Lab, Columbia, MO 65203

ACTION AREA: F Genetics, Molecular Biology, & Basic Physiology

SUMMARY: DNA Amplification-PCR (DAF) was successfully used for the first time in the identification of insect cell lines as well as host insects. This research resulted in a publication (Insect Molec. Biol. 5:187, 1996). DAF-PCR will provide a very valuable and reliable technique for identification purposes. It can be distinguish between several lepidopteran species including the heliothine.

NAME OF RESEARCHER(S) Dean Barry

AFFILIATION: USDA, ARS, University of MO

ACTION AREA: A Host Plant Resistance

SUMMARY: The objective of this program was to educate scientists from universities, industry ,and ARS about techniques for culturing insects and plants to evaluate transgenic plants for insect control. Personnel from all institutions were trained to efficiently obtain insects, how to handle them, manual infestations, culturing plants, design of experiments (to allow for biology of insects), evaluation of insect damage and yield of crop. The evaluation of transgenic corn cultivators were somewhat standardize and thus made for easier communications among the various institutions and EPA.

NAME OF RESEARCHERS(S): D. D. Hardee

AFFILIATION: USDA-ARS, Southern Insect Management Research Unit, Stoneville, Mississippi

ACTION AREA: B Chemical Control and Application Technology

SUMMARY: B.T. resistance monitoring of bollworm/budworm in transgenic cotton was initiated in 1996 and expanded in 1997. These tests show no significant increase in tolerance of these insects to the CryIA (c) protein expressed in transgenic cottons. These results were communicated to industry, consultants, and growers at six different meetings across the Cotton Belt in 1996 and 1997

NAME OF RESEARCHERS(S): M. R. Bell and D. A. Streett

AFFILIATION: USDA-ARS, Southern Insect Management Research Unit, Stoneville, Mississippi

ACTION AREA: E Biological Control

SUMMARY: A memorandum of understanding was established with the University of Arkansas to assess the effect of interspecific host plant variation on viral efficacy and persistence under field conditions. The persistence of the *Helicoverpa zea* nucleopolyhedrovirus (HzSNPV) on various cultivated or seasonal wild hosts of tobacco budworms and cotton bollworms was determined through field evaluation. Field persistence for HzSNPV on red clover, white clover, and velvetleaf was approx. 20% of the original five days after application.

NAME OF RESEARCHERS(S): M. R. Bell and D. A. Streett

AFFILIATION: USDA-ARS, Southern Insect Management Research Unit, Stoneville, Mississippi

ACTION AREA: E Biological Control

SUMMARY: The Autographa californica nuclear polyhedrosis virus (AcMNPV) is one of several candidate baculoviruses that have been selected for development of recombinant virus. E. I. Dupont de Nemours & Co. has several recombinant baculoviruses undergoing development that infect insect pest species of cotton. A CRADA has been established with the Southern Insect Management Research Unit (USDA/ARS) to evaluate recombinant virus production, field efficacy, and effects on non-targets. These recombinant viruses should provide better protection to cotton and offer another tactic to an integrated pest management (IPM) program.

NAME OF RESEARCHERS(S): M. R. Bell and D. A. Streett

AFFILIATION: USDA-ARS, Southern Insect Management Research Unit, Stoneville, Mississippi

ACTION AREA: E Biological Control

SUMMARY: An Area -wide management program with *Helicoverpa zea* nuclear polyhedrosis virus has been conducted in the delta to suppress the first generation of bollworm and tobacco budworm adults that are produced in non-cultivated early-season alternate hosts. In 1994-1995, a 215,000-acre test showed that one virus application could be accomplished at a reasonable cost, and that such treatment consistently reduced the number of moths emerging from weed hosts by >70%. Growers will be voting on a referendum for a grower -sponsored and grower-financed area-wide program in 1998-1999.

NAME OF RESEARCHER(S): H. R. Gross, J. J. Hamm, and J. E. Carpenter

AFFILIATION: USDA-ARS-SAA-IBPMRL

ACTION AREA: E Biological Control

SUMMARY: Beehive-mounted device developed for utilizing honeybees in the dissemination of biocontrol agents. A hive-mounted device was developed which forces honeybees exiting the hive to pass through a powdered formulation of a biocontrol agent such as the *Heliothis* nuclear polyhedrosis virus (HNPV). The honeybees disseminate the virus as they forage for nectar and pollen. September 29, 1994, the USDA obtained U.S. Patent No. 5,348,511 on a "Beehive-mounted device for utilizing honeybees (Hymenoptera: Apidae) in the dissemination of biocontrol agents". Although there was a great deal of interest among bee keepers around the world and some interest among plant pathologists interested in controlling pathogens that enter through flowers no one has obtained rights to the patent for production and sale of the device.

NAME OF RESEARCHER (S): G. W. Elzen

AFFILIATION: USDA, ARS, SARC, Weslaco, TX

ACTION AREA: B Chemical Control and Application Technology

SUMMARY: Various bioassays were used to characterize and evaluate resistance in tobacco budworm and bollworm. These data have been used in formulation of various state resistance management plans. (Ex). Ref-- Elzen, G. W., 1997 "Changes in resistance to insecticides in tobacco budworm populations in Mississippi, 1993-1995". Southwest Entomol. 22: 61-72.

NAME OF RESEARCHER(S): F. W. Plapp, Jr. and G. W. Elzen

AFFILIATION: Dept. of Entomology, TAMU and USDA, ARS, SARC respectively, Weslaco, TX.

ACTION AREA: B Chemical Control and Application Technology

SUMMARY: A team developed and tested an adult vial bioassay for monitoring resistance to insecticides in tobacco budworm and the bollweevil. This was the first demonstration of the vial test for non-pyrethroid insecticides or for monitoring the bollweevil. This bioassay provides near immediate results to determine resistance levels, and this information is currently being used in cotton insect control recommendations.

NAME OF RESEARCHER(S): G. W. Elzen

AFFILIATION: USDA, ARS, SARC, Weslaco, TX

ACTION AREA: B Chemical Control and Application Technology

SUMMARY: Laboratory studies established that pyrothroid resistance in tobacco budworm was a stable, co-dominant, male sex-linked factor with metabolic and target-site mechanisms. (EX.) Ref.- Elzen, G. W. et al., 1994, "Inheritance, stability, and reversion of insecticide resistance in tobacco budworm (Lepidoptera: Noctuidae) field populations". J. Econ. Entomol. 87: 551-558.

NAME OR RESEARCHER(S): G. W. Elzen

AFFILIATION: USDA, ARS, SARC, Weslaco, TX

ACTION AREA:

SUMMARY: Four insect predators, namely big-eyed bug, insidious flower bug, convergent lady beetle, and green lacewing were evaluated for tolerance to 10 insecticides, including four new insecticides with novel modes of action. Few studies of this nature have been reported, especially with newer insecticides. The data offers guidelines on proper timing and use of selective insecticides to preserve beneficial insects.

NAME OF RESEARCHER(S): Guillermo A. Logarzo

AFFILIATION: South America Biological Control Laboratory, USDA, ARS, Argentina

ACTION AREA: E Biological Control

SUMMARY: South America has a great potential for new biological control agents that can help *Heliothis/Helicoverpa* (H/H) management. More than 30 species of parasitoids have been imported into the U.S. from different parts of the world for biological control, however none of them came from South America. In Argentina alone there are 30 known species of H/H complex's parasitoids and intensification and extension of the explored areas are likely to provide more biological control agents.

A survey of parasitoids was made in Argentina to select new biological control agents for H/H complex. Eight parasitoids species were found. Two species were reared in a laboratory and one was imported from South America to U.S. Researchers are now evaluating the possible use of this parasitoid in the Stoneville Mississippi, quarantine facilities. This information is necessary to initiate studies in the areas of ecology and population dynamics and to develop technologies to managing H/H spp. using parasitoids.

In the future, our goal is to increase collecting efforts to increase diversity and quantity of cultural parasitoids. Also, more collection sites will be included, such as Bolivia and Paraguay.

A REVIEW OF AREA-WIDE MANAGEMENT OF *HELICOVERPA* AND *HELIOTHIS* (LEPIDOPTERA: NOCTUIDAE) WITH PATHOGENS (1987-1997)

D. D. Hardee, M. R. Bell[1], and D. A. Streett

Southern Insect Management Research Unit, USDA, ARS
Stoneville, MS 38776

ABSTRACT

Research to develop improved methods of managing serious insect pests of delta crops, specifically cotton, by use of natural insect pathogens was begun in 1987 at the USDA, ARS, Southern Insect Management Research Unit (SIMRU) in Stoneville, MS. Previous research had shown that non-crop plants, particularly early-season weeds, were hosts for the tobacco budworm, *Heliothis virescens* (F), and cotton bollworm, *Helicoverpa zea* (Boddie), prior to the presence of crop hosts. It was theorized that tobacco budworm and cotton bollworm populations could be managed by either controlling the insects on the weeds using insecticides, or by controlling the early season hosts themselves via herbicides or mowing. Since entomophathons (microbial insecticides) are considered to be among the safest methods of insect control, research was begun to investigate their use in a management scheme. Positive results of small field and cage tests (prior to 1990) led to large area studies, beginning with a 25,900-ha test in 1990, and culminating in 81,000-ha tests in 1994 and 1995. Tests over smaller areas in 1996 and 1997 were designed to (1) evaluate the effectiveness of a commercially-prepared formulation of the virus sprayed twice at weekly intervals (1996) and (2) determine efficacy of a half-rat of the new virus formulation in an attempt to reduce costs (1997). Collective results of this 11-yr study indicate that virus application can be accomplished at a reasonable cost, and that such treatment consistently reduced the number of moths emerging from weed hosts by >70%. Herein, we present brief results of the long-term study that led to the present question of what the future holds for this project.

INTRODUCTION

Stadelbacher (1979, 1981) discussed the importance of several early-season wild and domesticated host plants of the tobacco budworm, *Heliothis virescens* (F.), and cotton bollworm, *Helicoverpa zea* (Boddie), in the delta of Mississippi and their importance in the buildup of the first generation which subsequently invades cotton. The major early-season hosts of these insects, wild geranium, *Geranium dissectum* L. and *G. carolinianum* L., grow primarily in disturbed area such as ditch banks, roadsides, and tilled but unplanted fields, and are widely distributed in the Delta. Seed of both species germinates from mid-October through early spring, and flowers and sets fruit from mid-April to late-May. Larval feeding is restricted to the immature fruit. In a study of larval and adult populations, Stadelbacher (1979, 1981) calculated that an averaged of 450,000 *Heliothis* larvae and 17,000 adults were produced per hectare (2.47 acres) of wild geranium, and theorized that wide area control of the first larval generation could thus have a positive impact on the management of bollworm/budworm in crops such as cotton. Additional research showed that: 1) only 3.5% of the overwintering

Heliothis/Helicoverpa population survived to emerge as adults; 2) spring emergence of the overwintered population occurred 6 weeks before cultivated host plants were available; 3) surviving populations were restricted to and concentrated in early-season alternate host plants which occupied <5% of the total rural area; and 4) moths emerging from these wild hosts in early to mid-June moved into cotton (Knipling and Stadelbacher 1983; Snodgrass et al, 1991).
The rationale for attacking bollworm/budworm populations during the first seasonal generation, and possibly the second was addressed by Knipling and Stadelbacher (1983). Several methods for control of this larval generation were examined, but due to the large-area control needed, the use of safe, natural control methods such as microbial agents was deemed most appropriate for further study.

The most promising of the microbial agents available for use against first larval generation bollworm and tobacco budworm larvae on weeds was believed to be the baculoviruses [nuclear polyhedrosis viruses (NPV) and granulosois viruses], due to their safety, relative stability, and virulence. The baculovirus from the cotton bollworm (HNPV) was the first to be registered by the Environmental Protection Agency for use on row crops, and the safety studies conducted prior to registration were considered the most in-depth ever on any insect pathogen or insecticide. This virus occurs naturally in the proposed test area and is known to infect only insects in the genera *Heliothis/Helicoverpa.* Although this fact has relegated it to relatively few commercial markets, this virus has a potential infectivity such that the LD50 may be as low as a single polyhedron (one virus particle) per bollworm/budworm larva (Burges 1981). The negative aspects of baculoviruses include their slow activity and problems related to in field persistence of the virus.

Several reviews are available on various phases of this study (Hardee and Bell 1996a, 1996b, 1996c; Hardee and Bell 1997) but the following is a summary of research techniques, methods and materials, and general results for the entire 11-year study.

METHODS, MATERIALS, AND RESULTS

1987. Research by Bell (1988a) showed that an adult moth developed on approximately every 1-3m of early-season wild hosts. A dye-marking method was used to first examine the effect of NPV applications on the emergence of this generation of adults in 1987. In that study, half of field plots in an area were treated with a blue dye and ½ were treated with a red dye mixture. In another area, ½ of field plots were treated with blue dye and the other ½ with red dye plus *H*NPV at a rate of 6.0×10^{11} polyhedral inclusion bodies (PIB)/ha. Evaluation of the effects was determined using pheromone-baited cone traps (Hartstack et al. 1979). The first marked adult was captured on 18 May and the last on 21 June. Both red and blue marked tobacco budworm and bollworm adults were captured from areas around fields treated with either blue or red dye without *H*NPV. Only blue-dyed marked moths were trapped near fields treated with either the blue dye or red dye+*H*NPV. These results indicated a significant reduction in the number of budworms emerging from the virus-treated areas (Bell 1988b).

1988. A cage study was conducted during April and June to more accurately measure (although under caged conditions) the effectiveness of microbials in early-season control of bollworm/budworm (Bell 1991). This test consisted of three replicates of each of four microbial treatments and an untreated control. The four treatments examined were: NPV in water, NPV in aqueous 10% crude cottonseed oil formulation, NPV in a COAX®-dust formulation, and an

insect growth regulator (IGR) (SAN415WG354)+*Bacillus thuringiensis* (Bt)Berliner (SAN8101) formulation supplied by Sandoz Crop Protection, Inc. (Des Plaines, IL).

Fifteen screen cages (plastic insect screen, 4m x 8m x 3m tall) were erected over the early-season weeds, the canopy of which was approximately 100% wild geranium, primarily G. *dissectum*, but also containing some G. *carolinianum*. On 26, 27, and 29 April, each cage was infested with approximately 1,000 bollworm and 1,000 budworm larvae from our lab culture. Microbial treatments were applied on 2 May, when larvae were from 3-7 d old. All virus treatments were applied at a rate of 6×10^{11} PIB/ha, and the IGR-*BT* was applied at 112 gm (AI)/ha + 1.1 kg/ha. The NPV-oil, NPV-water and IGR-*Bt* treatments were applied in a volume equivalent to 46.9 l/ha using an atomizing sprayer held approximately 0.5 m above the plant canopy. The dust formulation was applied at a rate of 3.4 kg/ha using a small garden duster. Cages remained undisturbed from 2 May until 29 May, when the first adult was observed. Cages were then searched daily and numbers, species, and sex of moths were recorded. The first adult moth was captured 1 June, and the last on 15 June.

Virus treatments resulted in overall reductions in emergence of 80.7 to 91.2% (Bell and Scott 1989), with tobacco budworm emergence reduced 78.5 to 89.2% and cotton bollworm emergence reduced to 71.4 to 100%. Although the application of virus in water resulted in the greatest level of control of both budworms and bollworms (89.2 and 100% respectively), there were no significant differences due to formulation used. The overall number of moths per cage in the IGR + *Bt* treatment was significantly less than in the check. However, the level of control was significantly less than that obtained with any of NPV treatments. These tests indicated that *H*NPV was effective in reducing bollworm/budworm emergence, and would be a good candidate for use in management systems where pests develop on early-season wild hosts.

1989. The success of a large-area program utilizing early-season control methods mandated that the results obtained by hand application be reproduced using aerial application. Thus, a study was undertaken to examine the effectiveness of aerially-applied virus in controlling the emergence of bollworm/budworm adults from early-season host plants (Bell and Hardee 1991). The test was conducted in Washington County, Mississippi, with aerially-applied treatments consisting of three levels of NPV: 0, 50, and 100 larval equivalents (LE)/ha [one LE equals 6 billion polyhedral inclusion bodies (PIB)]. Treatments were applied in water on 27 April; untreated control plots were covered with plastic sheeting during application. Following application, screen cages (4 x 8 x 4m tall) were placed over each plot and secured.
Cage searches were conducted daily after the first moth was observed, and moths were captured and removed. Number, species, and sexes of moths were recorded.

The first adults were captured on 30 May and the last on 12 June. Budworm emergence was reduced 88% and bollworm emergence by 100% in plots treated with 100 LE/ha (Bell 1990), for a total average emergence reduction of 90%. The 50 LE rate caused reductions of 65% in budworms and 57% in bollworms, for an overall reduction of 64%. The mean total numbers of bollworms/budworm adults emerging all differed significantly from each other. The results of this test were therefore similar to those obtained when alternate host areas were treated by hand, indicating that a single aerially-applied *H*NPV treatment could result in a reduction in first-generation adult emergence of about 90%. However, a large-area test was needed to evaluate this technique as a management tool in the Mississippi Delta. Such a test was planned for 1990.

1990. The study consisted of aerially applying a viral insecticide (Elcar®, *H*NPV) to early-season alternate host plants of bollworm/budworm within a single area (16.7 x 16.7 km,

25,900 ha) at a time of maximum immature seed production in a majority of the wild geranium in the test area. Emerging adult populations would be compared to those in a similar, untreated area, separated by a 16.0 km buffer (Bell and Hayes 1994; Hayes and Bell 1994). The treatment area was in parts of Washington and Sunflower Counties in the Mississippi Delta. Spray coverage, infection rates of larvae on pre-season wild hosts, persistence of virus on plants, number and species of moths emerging from alternate hosts within the areas, and number and species of the first bollworm/budworm adult populations invading cotton were determined.

Since the treatment of a large, populated, non-crop area with a microbial pesticide was unprecedented, the reaction of the public to the project was of utmost concern. We believed, however, that an informed public would be an approving public. The strategy for the public information campaign was developed jointly by USDA scientists involved with the project, the USDA, ARS Information Office, Delta Council, and personnel of Sandoz Crop Protection, Inc. This successful information campaign was effective in minimizing possible problems associated with area-wide application of insecticides.

Virus was applied both by aircraft and by trucks equipped with mist blowers. Both methods of application were calibrated to deliver virus at a rate of 100 LE in 191 of water/ha. Since the plan was to treat only alternate host habitats, pilots attempted to treat only field edges, borders, fallow fields, treelines, etc. Water-sensitive cards were placed randomly among the weeds to determine spray coverage. Aerial application began on 24 April, a time believed to be about 7 days prior to maximum overall seed production in the G.*dissectum*. Aerial application was completed by 8 May, although much of the application was done during windy weather conditions not favorable to spot-spraying sites. A series of early spring weather fronts caused many farmers to delay tilling their fields, resulting in an unusual amount of weed areas where the appropriateness of treatment was questionable. Truck-mounted mist blowers (calibrated to deliver 20 l/ha along the side of the truck in a 18-m swath width at 8 km/h were used to treat along major roadways within the test area (560 km total) between 30 April and 4 May. Although these areas are known to be major sites for geranium (Stadelbacher 1982) they are more difficult to treat by aerial application, either because of vehicle traffic or nearby power lines.

Bioassays were made of field-collected materials to estimate the efficiency of the spray application and viral persistence. To estimate the quantity of the virus on the plants, G. *dissectum* terminals were cut at random from 8 plots in the treatment area as soon as possible after application. Terminals (72) from each locations were fed to 6-d-old tobacco budworm larvae for 48 hr, after which larvae were placed on artificial diet. Larval mortality was recorded 10 days after the beginning of the feeding period. A final bioassay was conducted on 29 May to determine the residual virus on the weeds. Random samples of remaining wild geranium were collected and fed to larvae as before, with 144 larvae fed material from treated plots and 144 fed material from untreated area.

The methods used for the cage tests were similar to those used in the previous study. Untreated control plots were covered with plastic sheeting during application. Daily searches were conducted within the cages after the first budworm/bollworm moth was observed, and moths were captured and removed. Pheromone traps were used to monitor the relative abundance and fluctuations in the adult male populations in the treatment and control areas. In both areas, four trap locations (1trap/species/location) were identified near cotton fields within each 1.6-mi interval/(radius) from the center. Additional sampling extended to 8 km in 16 km in the treatment area, to present an assessment of migration on the treated area. Depending on

availability of an accessible cotton field, attention was given to spacing trap locations in different quadrants. Trap locations consisted of 1 trap/species placed at the edge of a cotton field along an accessible roadway; traps were separated by about 35m. Because fields were frequently cultivated and roadsides are often mowed or burned, traps were placed near power poles and in other protected sites. Traps were routinely monitored from 1 April, which included the flight of the parental F_1 and F_2 generations.

In addition to the estimation of the emerging population by adult trapping, attempts were made to estimate the number of adults by counting the egg deposition on early hosts and cotton within the test areas. This method required visually checking plants for a total of 30 min in each sample area and recording the numbers and relative populations of budworm/bollworm eggs.

When *G.dissectum* terminals were randomly collected from 8 different plots immediately after aerial application and fed to 6 day old tobacco budworm larvae for 48 hours, mortalities at 10 days averaged 75.1% (67.7% to 88.7%) compared to a background mortality of 9.3% when larvae were fed terminals from untreated areas. Although the mortalities of larvae fed treated terminals were significantly greater than those fed untreated terminals; the 75.1% mortality was less than that reported in a previous study. In that study, the treated area was an open field, and the applications were made in broadcast fashion not to a strip target area. Larval mortalities in terminal bioassays averaged 95.7%. The random samples tested here were taken from along tree lines, field borders, etc., not from open fields. This lack of virus on the target hosts was also indicated by the number of droplets found on water-sensitive cards. A similar application rate and droplet size in the earlier test resulted in an average of 54.4 droplets per cm^2, whereas there was an average of 3.9 droplets per cm^2 in the present test, indicating a 93% reduction in droplets hitting the plants. When the larvae were fed terminals collected 1, 2, 3, 5, 7, and 9 days after treatment viral morality averaged 77, 69, 64, 57, 41, and 38%, respectively. Only 5% of larvae died from NPV when fed wild geranium collected from the treated area 18 days after all applications had been completed; samples from outside of the test area produced no viral mortality. Very little wild geranium remained viable by that date.

There was a 41% total overall average reduction in emergence in the treated cages (Table 1), indicating much less effect than in the previous tests where the least overall reductions were about 88%. In the previous study, however, moth emergence was reduced by 64% when the virus dosage was halved (50 LE/ac). The present bioassay data indicated that aerial application resulted in only about 28% as much virus on the plants as in the previous study. If these indications were real, the 41% reduction in moth emergence in this study was reasonable. These data all indicated that deposition of virus on the target area was a major problem in this test, even in the cage test areas where application was somewhat easier than in other host plant habitats.

Pheromone traps and egg counts were used to assess the degree of area-wide suppression achieved by early-season application of the *H*NPV. Eggs (F_2) were collected from cotton and other hosts to characterize the surviving reproductive populations. The effect of treatment was demonstrated by deviations in trap capture patterns within-year between treated and control plots and between years in the treated plot. Rates of increase (r_i) between generations were calculated by dividing the number of moths captured in one generation by the number from the previous generation. The results of these data (Bell et al., 1990) indicated that the single virus application reduced the adult budworm population emerging from early season alternate hosts by 25 to 38%, and the bollworm population by 19 to 31% in the 167-km^2 area. Overall budworm/bollworm adult emergence was reduced by 41% in cage test areas. Although the treatment failed to reduce

the adult population as much as expected, the results were still encouraging. This reduction in the number of moths was understandable when all factors of the study were taken into consideration, primarily the lack of spray coverage. A secondary factor was the timing of the application. Although aerial application studies had been done in which the virus was applied to alternate host areas, the conditions of this test were different in that much of the application had to be done under windy conditions. Bioassays were very informative in indicating the presence of the virus on the plants. Based on that data, the reductions in insect populations were comparable with prior tests. Although timing was less a factor than spray coverage, a 21-day application period was considered too long for most seasons.

1992. A repeat of the 1990 study was planned for 1991, but the test was canceled due to severe flooding during the spring of that year. A similar but smaller test was planned for spring of 1992 in which the goal was improved spray coverage. Preliminary tests in 1991 showed that the addition of 4% soybean oil w/emulsifier increased the amount of material reaching the surface from a spray as a "blanket" application would increase virus deposition on the early-season hosts.

The test site was 7,326 ha (4.8 km radius circle) in a 9.6 x 9.6 km area used as an untreated control during 1990 and 1991 tests. Data collected to determine spray coverage, infection rates of larvae on pre-season wild hosts, persistence of the virus on the plants, and the number and species of moths emerging from alternate hosts within the treated area and compared to the surrounding untreated area.

The virus was applied at the time of maximum immature G.*dissectum* seed production (24, 25, 27, and 28 April) using 4 fixed-wing aircraft, each calibrated to deliver virus at a rate of 100 LE/ha in 9.31 of water containing 4% crop oil spray additive. The lead aircraft was equipped with an electronic satellite guidance system, which recorded the aircraft's position relative to the earth's surface. The three other aircraft followed.

Bioassays were conducted on G.*dissectum* collected at various times from various locations within the treated area to estimate the efficiency of the spray application and the persistence of virus on the wild geranium. Six-day-old tobacco budworm larvae were allowed to feed on terminals for 48h (60 larvae, 4 samples/location and time), after which they were then placed on clean artificial diet. Larval mortality due to virus was recorded 10 days after the beginning of the feeding period. The first samples were collected on 27 April and the final collected on 13 May.

Cage studies for evaluating the effectiveness of the virus application were as described previously. A total of 12 cages (6 treated and 6 untreated control were erected in pairs. The control plots were covered with plastic sheeting during application, as in previous tests. Searches were conducted daily within the cages after the first moth was observed, and the number and species of moths captured were recorded.

Pheromone traps were used to monitor the relative abundance of the adult male bollworm/budworm populations in the treatment area (center 4.8-km radius) and the untreated area (the area surrounding the treated area and 4.8-9.6km from center of the test area). In both areas, 26 trap locations (1 trap/species/location) were identified near cotton fields, with 8 to 9 pairs within each 1.6km interval/radius from the center (total area encompassed in a radius of 9.6km). Traps were routinely monitored from 20 March to 31 August.

Allowing tobacco budworm larvae to feed for 48 h on G.*dissectum* terminals collected 0, 2,3,4,6,7,8, and 11 d after treatment produced virus-induced mortalities of 83, 81, 60, 79, 75, 67, 60, and 33% respectively. Samples collected in the treated area on May 13 (17 d after treatment)

did not produce viral mortalities greater than the samples from untreated areas. These results tend to verify the improved coverage obtained in this study compared to the 1990 study, since mortalities were consistent over the areas tested. The indicated persistence of the virus also compared well with that previously reported, again indicating roughly 47% of the original activity remaining 9 days after application as reported in previous tests.

Cage data indicated that the affected generation of adults (that generation developing as larvae on the wild hosts) began emerging on 3 June (bollworm) and 12 June (budworm). A total of 36 budworms and 13 bollworms emerged in the 6 untreated areas, compared to 7 budworms and 7 bollworms in the 6 treated areas. The cage data, therefore, indicated a significant reduction in budworm emergence (80.6%) in treated areas compared to untreated hosts (Table 2). Although the bollworm emergence was 46.2% less in the treated cages, the difference was not significant.

Pheromone trap data indicated similar populations of both species within the treated and untreated areas until 3 June, after which there was as observed period of reduced response within the treated area, particularly the center 4.8 km radius or 9.6 km dia. Emergence of adult budworms in the cages indicated the population emerging from 12 through 26 June most likely developed as larvae on the early season hosts. During that period, budworm traps in the 9.6 km diameter treated area averaged 8.0 moths/trap/night (Table 3) compared to 11.4 moths/trap/night captured in the untreated area (5-10 km from the center of the test), a reduction of 29.8%. However, captures averaged 6.4 moths/trap/night in the middle 6.4-km diameter of the treated area, a reduction of 43.9% in that portion of the virus treated area compared to the surrounding untreated area.

The indicated reduction in budworms within the center of the test (43.9%) was an improvement over the results obtained in 1990, but the effectiveness indicated by trap data was not as good as that shown by the cage data. This difference may be explained by immigration of moths from outside the test area, reducing the indicated effectiveness of the virus application based on trap data. Red-dye-marked moths from another program were being released at least 13-km from our test area. Trap captures in part of our test area averaged up to 33% marked moths during the release period, indicating significant movement of moths into the area. It is, therefore, reasonable to speculate that the actual reduction in budworm moth emergence from early season hosts was greater than ~43.9% shown by the adult captures.

1994. An area-wide, early-season pest management test was conducted utilizing a 505-km^2 area, or twice the diameter of the 1990 test. Since no commercial virus was available, over 8 million cotton bollworm larvae were reared over a four-month period to produce enough of an EPA-labeled insect virus to treat 87,000 ha. Application of the virus to 79,000 ha was made from 28 April through 3 May using contracted private aircraft equipped with satellite global positioning systems. Although the virus and formulating materials were tested and shown to have no effect on catfish, spray nozzles were turned off over those areas.

Evaluation of the effects of the virus application was accomplished using several methods: pheromone trapping in the treated area compared to traps in three similar untreated areas of the delta; cages placed over treated and untreated weed hosts as in previous tests; plant bioassays (feeding plant materials to 6-day-old larvae); and examining plants in selected fields within the treated area compared to the three untreated areas for differences in eggs or larvae.

Pheromone trap counts of budworm and bollworm moths in the treated area between June 10 and August 22 averaged 53% (17 to 91%) less than traps in three similar, untreated areas

(Figs. 1 and 2). A total of 195 tobacco budworms emerged in 12 cages over untreated areas compared to 80 emerging in cages over treated areas, a reduction of 59%. Four bollworm moths emerged in treated areas compared to 11 in untreated areas, a reduction of 64%. Virus-induced mortality of 57 larvae collected from weeds in two locations three days after treatment was 85%. Bioassay data showed that 76% of larvae fed treated terminals for 48 h (average of 22 samples of weed samples collected after application had dried, 30 larvae/sample) died from virus infection. The cost of virus production and application was about $449,162 or $5.54/ha. Although the adult trapping counts and infection data appeared to support the significant effect of virus in reducing bollworm and budworm populations in the area, reports on cotton scouting and a possible economic impact comparing the treated area to the untreated areas did not show any positive benefit. Furthermore, counts of larvae and eggs within the treated area were equal to the untreated areas.

1995. As in 1994, over 8 million cotton bollworm larvae were used to produce virus to treat over 81,000 ha and evaluate the effect of such a treatment on the resulting populations of bollworms and budworms. The virus was likewise applied using contracted private aircraft with global positioning systems to treat the same area as was treated in the 1994 test. In 1995, the virus was applied from 5 May through 10 May 1995, approximately one week later than in 1994. Evaluation methods were similar to those used in 1994, with slight modifications. First, a total of 398 tobacco budworm larvae were collected at various times from weed hosts in 21 locations. Second, pheromone traps were placed in the treatment area plus the one check area which in 1994 had captures closest to the average of the three check areas used that year. Planned cage tests were lost due to circumstances of application. An evaluation based on examinations of cotton fields for presence of eggs and larvae was conducted.

The mortality of the collected larvae due to virus infection by date of collection is shown in Table 4. It was impressive that the larvae collected on 11 and 12 May were all infested (100% mortality due to virus). By the next week, the percentage of infected larvae decreased; but by that time, many of the infected larvae would have been dead and therefore would not have been collected. The persistence of virus over the following 10 days could indicated disease transmission from diseased and dying larvae to previously-uninfected larvae. In 1994, overall counts of tobacco budworm and bollworm moths in the treated area between 10 June and 22 August averaged 53% less than in traps in the untreated area. During the same period in 1995, the overall counts averaged 66% less in the treated areas (Table 5). Trap captures of tobacco budworms and bollworms are illustrated in Figures 3 and 4. We expected the effects of the early virus treatment to be expressed during the emergence of moths in the June generation. That is what was indicated by the 1994 H. *virescens* trap captures (7 June through 8 July). The 1995 trap data not only indicated the reduction in June, but may have also indicated continued reductions through the July population. Although we felt that the timing of our application was too late to cause reductions of the first population of H. *zea*, trap capture data suggest this was not the case. We found larvae easily during the period of 11 May - 19 May, and the amount of virus on the plants from dying budworm larvae might have affected the bollworms if they were in a second generation at that time.

1996. A circular treatment area with a 5.6 km radius was established at N 90° 48' 38" W 33° 19' 00" that encompassed approximately 9,972 ha. The HzNPV formulation used in this study consisted of Gemstar™ LC (biosys, Inc.) diluted in water with an equal volume of Soysurf™ (Sanders Seed Co., Cleveland, MS) and applied at an application volume of 2.33 liters

per ha. Aerial applications of virus were applied at a rate of 4.94×10^{11} occlusion bodies (OB's) per ha to the entire area on two separate occasions (30 April and 9 May). These two dates were selected to coincide with the larval emergence of bollworms and tobacco budworms, respectively.

Twelve enclosure cages (26.8 m^2 x 1.8 m high) were set up in a randomized complete block design of three replicates with four treatments at two locations. Treatments within each replicate were an untreated control; early virus treatment only; late virus treatment only, and both virus treatments. A single cage was used for each treatment and each cage was monitored daily for adult emergence from May 20 until June 10. Earlier studies have shown that each enclosure cage isolated a representative sample of tobacco budworm and bollworm larvae. The number and species of moths emerging in each cage were recorded for data analysis.

Sampling transects ran from the study site center, bisecting the circle and extending for 8 km beyond the study site boundaries. Sampling sites were located every 1.6 km along the transects with two (one each for bollworm and tobacco budworm) standard cone traps (Hartstack et al. 1979) established at each site. Trap contents were sorted for identification and counted three times each week over the 12-wk period following virus application.

Overall adult emergence among all the treatments in the study area was low, and this was attributed to the low moth populations observed in the area. The low rates of adult emergence precluded any statistical analysis of the data.

Mean total trap captures per week for the four sampling sites along the transect near the center of the virus treatment area (treated) and at the four sampling sites along the transect that were furthest from the center of the treatment area (control) are presented in Figure 5. H. *Zea* was the predominant species with >90% in the control and treated area. Tobacco budworm moth captures in the center of the virus treatment area averaged 21 moths/trap/week versus 268 moths/trap/week in the untreated area during peak trap capture. This represented a 92% reduction in tobacco budworm moth captures. Trap counts for bollworms in the center of the virus treatment area were 9% lower than moth captures in the surrounding untreated areas.

Results from the pheromone trap capture data suggest that the virus application was less effective at reducing bollworm moth emergence then tobacco budworm moth emergence. Timing of application or movement into the treatment area were considered to be the primary factors responsible for the observed lack of reduction in bollworm moth emergence in the treatment area. The pheromone trap sites reported for the treatment area were only 6 km from the border of the treatment area. Movement of 8 km and upwards to 19 km has been reported for H. *virescens* and H. *zea*, depending upon environmental conditions (Hayes 1991). This degree of movement could have a significant impact on any attempt to evaluate the success of the 1996 area-wide program using pheromone trap capture data.

1997. The impact of a lower virus application rate (approx. 20 larval equivalents) was evaluated during the 1997 field season. A circular treatment area was established near Bourbon, MS with an 8 km radius that encompassed approximately 40,485 ha. Plots of wild geranium were established at two locations in the treatment area in a RCB design with four replicates of each treatment. Each replicate consisted of four plots ($12m^2$) with plot borders mowed to facilitate cage installation following virus application. Two plots within each replicate were artificially infested with laboratory-reared neonate larvae (100 bollworm and budworm larvae) on four separate days prior to application. Treatments within each replicate consisted of an untreated naturally-infested control, a naturally-infested virus treatment, an artificially-infested control, and

artificially-infested virus treatment. Each plot was covered with a cage composed of plastic insect screen (4m X 8m) after virus application.

The HzNPV formulation used in this study consisted of Gemstar™ LC (Thermo Trilogy, Inc.) diluted in water with an equal volume of cotton seed oil (PBSY) with an emulsifier (Quality Limited Products) and applied on 4-6 May 1997 at an application volume of 2.4 liters per ha. Aerial applications of virus were applied at a rate of 2.47 X 10^{11} occlusion bodies (OB's) per ha to the entire area. Untreated control plots were covered with plastic during the virus application.

Data from the 1997 area-wide study have yet to be analyzed. Preliminary data indicate that overall coverage averaged 85% in the treated area. A reduction in overall adult emergence among the virus treated cages with a natural infestation averaged ca. 83%, whereas virus treated cages that had been artificially infested showed an 81% reduction in adult emergence. The trap count data have not been analyzed at this time.

DISCUSSION

All studies have shown that application of baculovirus (NPV) to early-season hosts of the tobacco budworm and cotton bollworm resulted in reduction in the numbers of adults that emerge from treated areas compared to adjacent untreated areas. This fact is demonstrated both by the significant reduction in the numbers of moths in cages placed over treated areas (compared to untreated areas), and by the infection rates of larvae collected from treated early-season weeds. Based on those results, we estimate that a properly timed NPV treatment with good coverage consistently resulted in viral-induced mortality of at least 70% and possibly as high as 100%.

In the largest tests (1994 and 1995), the rates of infection of larvae on the hosts as well as the reduction shown in moth emergence did not translate to a significant difference in the number of eggs/larvae on the cotton in the treated area compared to the surrounding untreated areas. During both years, number of adults during the crop season in the entire area of the study was relatively low. Much of the theory regarding the use of this pest management system is related to the distance and timing of moth flights. One indication of significant moth movement was recapture in traps of several moths released in a sterile hybrid study (Laster et al., 1996) at least 13 km from the virus area. Mobility of the target pest makes evaluation of the success of suppression tactics difficult over large areas of the agroecosystem, and it will definitely play a part in the use of this method as a management tool. In addition, because the area under study had a history of the highest numbers of these insects in the Delta, movement from the treated area to untreated areas may have been reduced.

Although the virus used in 1994-1995 was produced at the laboratory in cooperation with the USDA-ARS Gast Rearing Laboratory at Mississippi State University, the new commercial formulation performed well in 1996-1997. However, due to the current methods of virus production, any producer of NPV will need considerable lead time between the order for large amounts of the virus and the expected delivery date.

A grower-funded program for managing *Heliothis/Helicoverpa* has been discussed for the Mississippi Delta in 1998 that would encompass approximately 324,000 ha. A conservative estimate on the amount of cotton planted in this area would be approximately 91,000 to 101,000 ha of cotton although this amount may vary by 20% for a given year. The total grower contribution per cotton hectare can be calculated by determining the total cost of the program and dividing by the total amount of cotton planted in the treated area.

The estimated cost for aerial application of the virus would range from $1.24 to $1.73 per ha and the cost for the oil adjuvant would be approximately $1.06 per ha. Thus, the estimated total cost for the aerial application and oil adjuvant would not exceed $2.79 per ha. Virus costs would range from $4.94 to $6.18 per ha depending upon the quantity purchased. The estimated total cost for the program in the proposed area would be $8.97 per ha or $2,906,000. If we assume that the cotton acreage represents 31% of the total area in the treatment program then the estimated cost per hectare of cotton would be $28.70 ($11.61 per cotton acre).

In the Mississippi River Delta, noncropped areas consist mostly of disturbed margins of cultivated fields or the shoulders of roads. Wild geranium is very abundant in this relatively small noncropped area, and here it serves as an excellent host plant for the tarnished plant bug, and as the main host for the first generations of the bollworm and tobacco budworm. Small plot research has shown that bollworm and tobacco budworm populations can be reduced by as much as 97% with one mowing and by 99% with one herbicide application. Mowing can reduce plant bud adult levels by 40% and nymphs by 79%, while a herbicide treatment can cause reductions of 65% for adults and 73% for nymphs. Both control methods have been tested only in small plots, and the effects of the treatments on pest and beneficial arthropods found in the noncropped areas has not been evaluated by large areas. Any supplemental mowing or herbicide treatments by growers would be an added benefit.

With the anticipated planting of large acreages of transgenic cotton in the future to control bollworm/budworm, a grower funded program to control the same pests is less likely to occur. This program, however, is available as a management tactic in the future if transgenic cotton does not perform satisfactorily. Additional benefits of area-wide sprays of virus include a reduction in numbers of these insects in corn, grain sorghum, and soybean.

LITERATURE CITED

Bell, M. R. 1988a. *Heliothis virescens* and H. *zea*: Feasibility of using oil-soluble dye to mark populations developing on early-season host plants. J. Entomol. Sci. 23: 223-228.

Bell, M. R. 1988b. Oil -soluble dyes for marking and estimating the effectiveness of microbial control of *Heliothis* spp. Developing on early season wild geraniums. Proc Beltwide Cotton Prod. Conf., pp. 254-257.

Bell, M. R. 1990. Use of baculovirus for the control of Heliothis spp. In area-wide management programs. Proc 5th Inter. Coll. For Inv. Pathol.

Bell, M. R. 1991. Effectiveness of microbial control of *Heliothis* spp. Developing on early season wild geraniums: Field and field cage tests. J. Econ. Entomol. 84: 851-854.

Bell, M. R., and W. P. Scott. 1989. Microbial control of *Heliothis* spp. Developing on early-season hosts: a cage study. Proc. Beltwide Cotton Prod. Conf., pp. 266-368.

Bell, M. R., and D. D. Hardee. 1991. Spray efficiency of aerial application of a nuclear polyhedrosis virus in area-wide treatment of early season hosts of bollworm/budworms. Proc. Beltwide Cotton Prod. Con., pp.624-627.

Bell, M. R., and J. L. Hayes. 1994. Area-wide management of cotton bollworm/tobacco budworm through application of a nuclear polyhedrosis virus on early-season alternate hosts. J. Econ. Entomol. 87: 53-57.

Bell, M. R., D. D. Hardee, and E. A. Stadelbacher. 1990. Management of cotton bollworm/ tobacco budworm populations through area-wide application of nuclear polyhedrosis virus on

early-season hosts. Proc. Soviet/American Symp. On Cotton IPM, Sept. 1990, Tashkent, Uzbekistan, USSR. In Press.

Burges, H. D. 1981. Strategy for the microbial control of pests in 1980 and beyond. In Microbial Control of Pests and Plant Diseases, 1970-1980. H. Burges (ed.), Academic Press, NY.

Hardee, D. D., and M. R. Bell. 1996a. Six years of area-wide management of bollworm/ budworm with pathogens – what does it mean and where do we go from here. Proc. Beltwide Cotton Prod. Conf., pp. 897-902.

Hardee, D. D., and M. R. Bell. 1996b. Area-wide management of *Heliothis/Helicoverpa* in the delta of Mississippi – 1994 program. *In* Challenging the Future. Proc. World Cotton Res. Conf., Brisbane, Australia, pp. 434-436.

Hardee, D. D., and M. R. Bell. 1996c. Area-wide management of bollworm and budworm with pathogens, p. 155. *In* S. Lynch, C. Greene, and C. Kramer-LeBlanc (eds.). Proc. 3rd National IPM Symposium/Workshop. USDA Misc. Publ. No. 1542, 300 pp.

Hardee, D. D., and M. R. Bell. 1997. Area-wide management of bollworm/budworm with pathogens – results of six-year project and projections for the future. Recent Res. Dev. In Entomol. 1: 105-114.

Hartstack, A. W., J. A. Witz, and D. R. Buck. 1979. Moth traps for the tobacco budworm. J. Econ. Entomol. 72: 519-522.

Hayes, J. L. 1991. Elemental marking of arthropod pests in agricultural systems: Single and multigenerational marking. Southwest. Entomol. 14: 37-47.

Hayes, J. L., and M. R. Bell. 1994. Evaluating early-season baculovirus treatment for wide-area suppression of *Heliothis/Helicoverpa*. J. Econ. Entomol. 87: 58-66.

Knipling, E. F., and E. A. Stadelbacher. 1983. The rationale for area wide management of .....
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Table 1. Number of moths emerging from G. *dissectum* after treatments with NPV (1990).

Treatment	No moths per cage, mean ± SEM[1]		
	H. virescens	*H. zea*	Totals
Untreated	8.11 ± 1.31 a	1.44 ± 0.56 a	9.56 ± 1.23 a
Aerial application	5.00 ± 1.76 b	0.67 ± 0.37 ab	5.67 ± 1.75b
LSD	1.47	1.08	3.32

[1]n=9 cages/treatment. Values within columns followed by the same letter are not significantly different (P>0.05, Fisher's LSD).

Table 2. Bollworm and budworm emergence from G. *dissectum* aerially treated with NPV[1] (1992).

	H. virescens	*H. zea*
Treated	1.17* ± 0.4	1.17 ± 0.7
Untreated	6.33 ± 1.7	2.21 ± 0.9

[1]Values represent numbers of moths emerging per cage (6 cages/treatment). Means denoted by * are significantly different from the control (P=0.05).

Table 3. Mean number of budworm captures by pheromone traps per night within treated and untreated areas of the Mississippi Delta in 1992.

	6/12	6/15	6/17	6/19	6/22	6/24	6/26	x
Untreated Area*	6.58	14.79	14.83	15.96	9.22	9.92	8.23	11.36
Treated Area A *·**	4.83	11.36	10.65	11.83	5.92	6.12	5.31	8.00
Treated Area B†	3.35	10.00	7.92	11.35	4.49	4.42	3.26	6.40
Prob. Of sig. diff. between Treated A and untreated (X^2)‡	0.72	0.47	0.98	0.22	0.76	0.88	0.76	

*The treated area (center 3-mi radius) received an aerial application of bollworm NPV on 24-28 April at a rate of = 99 Le/ha.
**Data based on 26 traps in each area. Treated Area A = 4.8 radius area. Untreated area = 4.8 to 9.6 mi radius area surrounding treated area.
†Data based on 13 traps located in center 3.2 km radius of treated area (Treated Area B).
‡Probabilities of significant differences based on frequency distributions (Chi-square test).

Table 4. Mortality due to NPV in budworm populations collected from treatment area. Virus treatment applied 5-10 May 1995[1]

Collection date	#Larvae collected	#Larvae killed by NPV	%NPV mortality
11 May	25	25	100
12 May	20	20	100
15 May	86	40	47
16 May	122	59	48
17 May	114	54	45
19 May	18	8	44
22 May	5	4	80
23 May	8	5	63
Total/overall	398	215	54

[1]Samples represent larvae collected from 21 of the 25 treated sectors.

Table 5. Pheromone trap counts, 20 traps/species/treatment (1995).

Dates	# Trap nites	Species	Treated		Untreated		
			Total # moths	x̄ Moths/ trap/nite	Total # moths	x̄ Moths/ trap/nite	% Reduction
6/7-7/8	35	*H. virescens*	6,084	8.69	15,205	21.72	59.99
		H. zea	8,538	12.20	20,566	29.38	58.48
7/12-8/16	39	*H. virescens*	15,589	19.99	21,744	27.88	28.31
		H. zea	12,547	16.09	34,181	43.82	63.29
6/7-8/16	74	*H. virescens*	21,673	14.64	36,949	24.97	41.34
		H. zea	21,085	14.25	54,747	36.99	61.49
6/7-8/16		Total moths	42,758		91,696		53.37

Dates	# Trap nites	Species	Treated		Untreated		
			Total # moths	x̄ Moths/ trap/nite	Total # moths	x̄ Moths/ trap/nite	% Reduction
6/7-7/12	38	*H. virescens*	2,725	3.59	8,245	10.85	66.95
		H. zea	1,867	2.46	5,696	7.49	67.22
7/14-8/16	35	*H. virescens*	6,559	9.37	16,275	23.25	59.70
		H. zea	11,375	16.25	35,622	50.89	68.07
6/7-8/16	73	*H. virescens*	9,284	6.36	24,520	16.79	62.14
		H. zea	13,242	9.07	41,318	28.30	67.95
6/7-8/16		Total moths	22,526		65,838		65.79

H. virescens Trap Captures, 1994

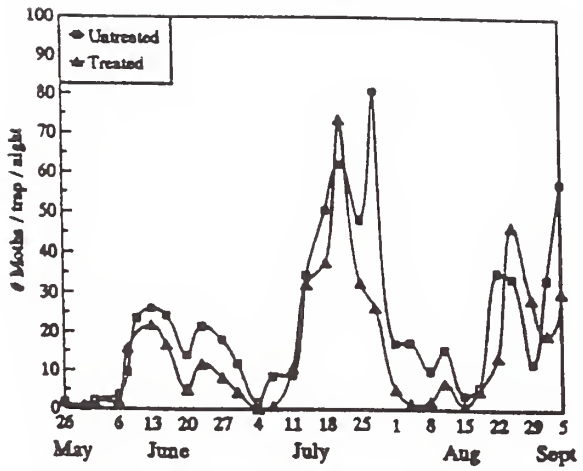

Figure 1. Pheromone trap counts of adult male budworms captured in the treated vs untreated areas.

H. zea Trap Captures, 1994

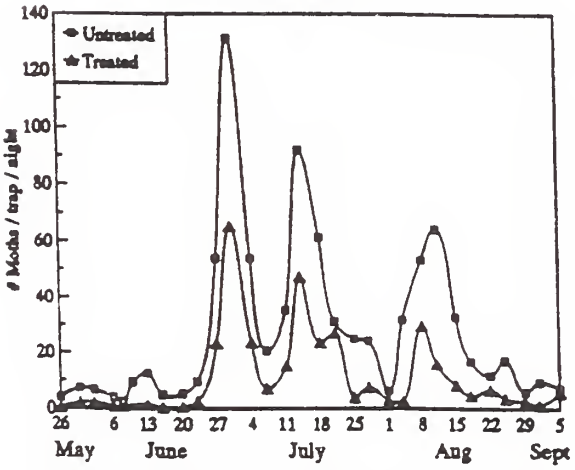

Figure 2. Pheromone trap counts of adult male bollworms captured in the treated vs untreated areas.

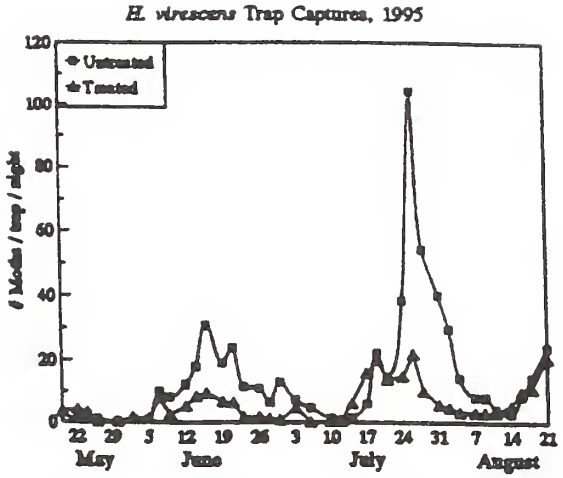

Figure 3. Pheromone trap counts of adult male budworms captured in the treated vs untreated areas.

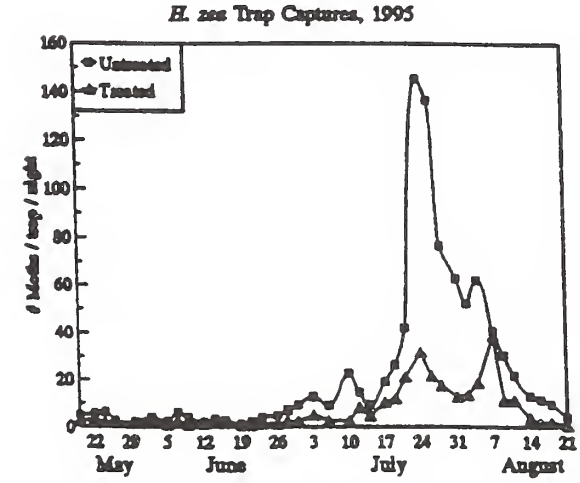

Figure 4. Pheromone trap counts of adult male bollworms captured in the treated vs untreated areas.

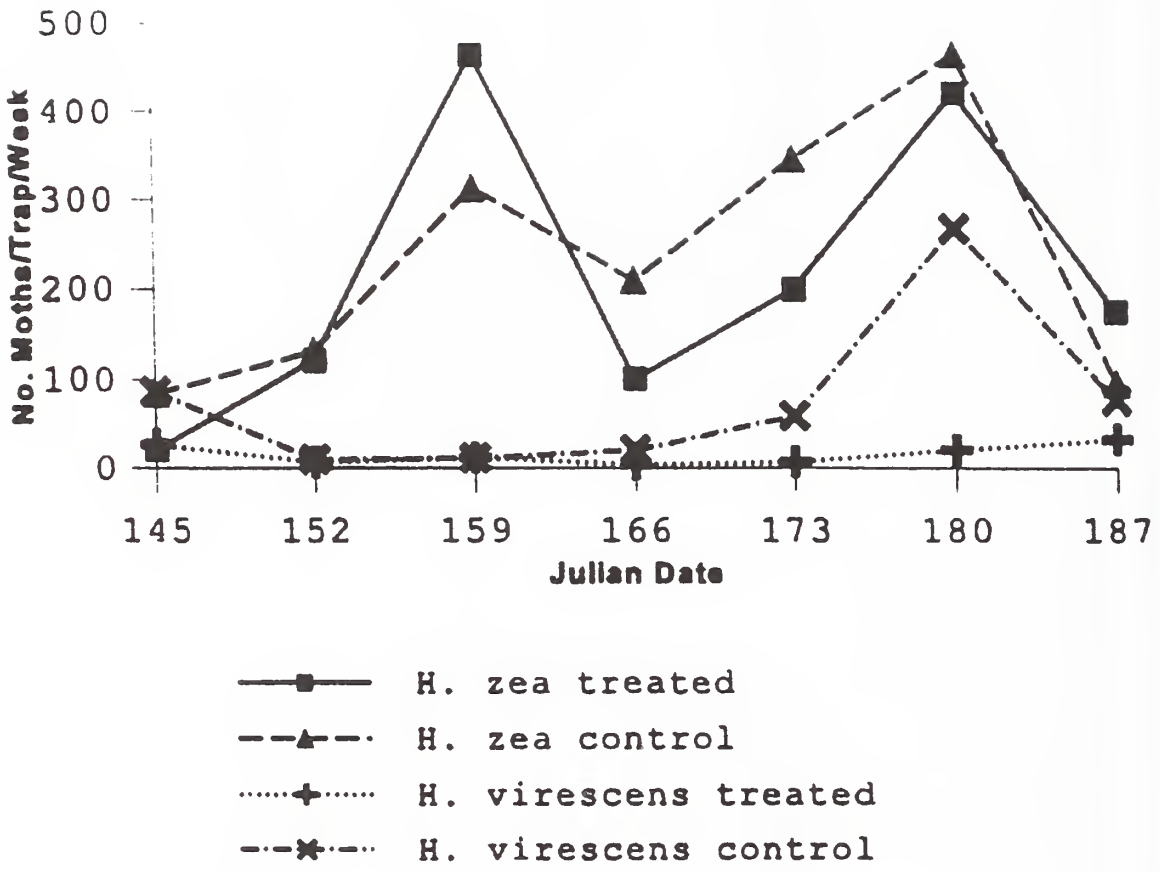

Figure 5. Mean Pheromone trap captures per week for *H. virescens* and *H. zea* in 1996

MOVEMENT AND MIGRATION OF *HELIOTHIS* AND *HELICOVERPA*

J.K. Westbrook[1], J.R. Raulston[2], W.W. Wolf[3], and P.D. Lingren[3]

Introduction

The bollworm, *Helicoverpa zea* (Boddie), and the tobacco budworm, *Heliothis virescens* (F.), are serious pests of U.S. agriculture. One of the key traits of these pests is their ability to fly surreptitiously. Because adult bollworms and tobacco budworms fly at night their movement is very difficult to detect. Further, flights of *Heliothis/Helicoverpa* (H/H) often occur well above 100 m altitude (Glick and Noble 1961; Callahan *et al.* 1972) where current technologies are rarely able to detect their activity. Much of the evidence of long-distance movement of these species is circumstantial, based on premature or precipitous captures of the pests in light traps or pheromone traps (Hartstack *et al.* 1982).

The movement and migration factor can play an unusual, yet key, role in the degree of success of H/H suppression. Movement and migration may act as catalysts which can undermine crop protection and increase control costs and the number of applications. Previous large-area pilot projects have indicated that movement may have accounted for significant variability of the test results (Schneider *et al.* 1989) or control efficacy (Hayes and Bell 1994). Management strategies must account for pest movement between native habitats and treatment areas, and throughout susceptible production areas. Insects disperse to find food, shelter, mates, and oviposition sites, especially in monoculture environments where the senescence and harvest of crops is very synchronous within a production area. Several excellent reviews cover the ecology and migration of H/H and other noctuid species (Stadelbacher *et al.* 1986; Farrow and Daly 1987; Fitt 1989; King 1994; Johnson 1995; Raulston and Slosser 1995; Reynolds *et al.* 1997).

Knipling and Stadelbacher (1983) proposed areawide management strategies for H/H based on concerns that farm-by-farm pest management requires individual producers to react to infestations of H/H species, which can readily move among a variety of adjacent or distant host habitats. Also, the Knipling and Stadelbacher proposal asserts that effective and economical control may best be achieved by proactively treating H/H within a smaller overwintering area than reacting to infestations which develop during the growing season on a continental scale. Additionally, this pest management concept would reduce the pool of resistant individuals which might otherwise lead to late-season control failures, and reduce the augmentation of local populations by migrants such that economic thresholds would rarely be surpassed.

The goal of this paper is to identify progress regarding research investigations of H/H movement and migration which has occurred since the previous H/H Research Conference held in 1993

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[3]USDA, ARS, retired

(Westbrook *et al.* 1994a). To achieve this goal, the authors address the state of knowledge, knowledge gaps, new technologies to monitor movement and migration, and opportunities for areawide management of H/H.

Characteristics of Dispersal Flight

Knowledge of H/H flight characteristics has been acquired from ground-based, night-vision observations of flight in the lowest 100 m of the atmosphere. Field observations of H/H flight have been made using night-vision equipment and infrared (IR) illumination (Lingren and Wolf 1982). Lingren et al. (1995) observed that released bollworm moths ascended in spiral flight to altitudes above 100 m, and proposed that bollworm moths may have used spiral take-off flight to determine directional orientation. Insect flight above 100 m altitude is based primarily on in-direct remote sensing measurements.

Radar has advanced the knowledge of H/H flight above 100 m altitude more than any other remote sensing tool. Although present radar technology is unable to identify H/H targets, awareness of the maximum detection range, size of the target's reflected image, and speed of the target reduces the set of candidate targets. Further, most radar field measurements have been made when assessments of the local population dynamics have predicted peak emergence of H/H from a monoculture habitat (Raulston *et al.* 1992). Automatic target-classification radars are being developed in the U.K. (Smith *et al.* 1993) and Australia (Drake 1993). Species identification of targets may not be attainable by single-wavelength radars (Drake 1991), due to intra-species variation of radar cross-sections of insects (Wolf *et al.* 1993).

Radar entomological studies have reported numerous characteristics of H/H flight above an altitude of 100 m. Radars have shown that bollworm moths depart en masse from mature corn at about 0.5 hours after sunset. Bollworm moths ascend to altitudes of 1200 m at a rate of about 1 m/s during the early evening (Wolf *et al.* 1993). Frequently, bollworm moths in the south-central U.S. congregate within narrow atmospheric layers which may coincide with the altitude of maximum wind speed (low-level jet) (Wolf *et al.* 1986a). Relatively dense layers of bollworm moths may align collectively at an acute angle to the prevailing wind direction. Vector subtraction of wind velocity (speed and direction) from bollworm displacement has yielded a mean migratory flight speed of approximately 5 m/s (Westbrook *et al.* 1994b). The mean angle between insect heading and wind direction is often more than 25 degrees (Wolf *et al.* 1995), and may be affected by wind direction, cloud cover, geographic location, and season. Multiple entomological radars operating along the border of Mexico and the U.S. from Moore Air Base (Mission, Texas) to Del Rio, Texas, noted similar levels of nocturnal insect flight activity along this 300-km transect in March suggesting an expansive insect source area (W.W. Wolf, unpublished data). Multiple-radar deployments have also revealed the predictable passage of insect "clouds" from the LRGV to locations 100 and 200 km downwind (W.W. Wolf, unpublished data).

An airborne radar system was used to determine the long-distance flight of a dense 'cloud' of bollworms which had emigrated from 200,000 ha of irrigated corn in the Lower Rio Grande Valley (LRGV) of Mexico and Texas (Wolf *et al.* 1990). Making repeated transects through the dispersing 'cloud', the airborne radar measurements indicated that the bollworms had migrated more than 400 km in 7.7 hours. Such flight displacement could have delivered migrants from the LRGV to a large

area of attractive host plants in the Winter Garden, Coastal Bend, and east-central regions of Texas.

Atmospheric trajectory analyses have estimated source and recipient areas (Westbrook *et al.* 1995b) of migrating H/H. Westbrook et al. (1990) estimated aerial pathways of pyrethroid-resistant tobacco budworms which may have infested cotton fields in western Texas in 1985. Mylar balloons (tetroons) were tracked to measure nocturnal wind trajectories at modal insect flight altitudes and estimate the flight pathways and geographic range of migrating bollworms (Westbrook *et al.* 1995a). Insect traps have been attached to drifting tetroons and hot-air balloons in an attempt to capture migrating H/H (J.K. Westbrook, unpublished data).

Pollen and other biological markers found on adult bollworms (Hendrix *et al.* 1987) captured in pheromone traps have been used to validate estimated insect trajectories. Lingren *et al.* (1994) found citrus pollen on adult bollworms captured in Oklahoma and determined that moths must have flown from source areas in Mexico or countries in the Caribbean Basin. Other pollens found on the adult bollworms in Oklahoma corroborated the conclusion of distant source areas (Lingren *et al.* 1993). Estimated early-season migration of bollworms from the Lower Rio Grande Valley (LRGV) of northeastern Mexico and southern Texas was well correlated with daily captures of bollworms in pheromone traps across south-central Texas, especially to bollworms marked with citrus pollen (Westbrook *et al.* 1997a). Adult bollworms were marked internally by consuming a sucrose solution with *Lycopodium clavatum* spores that was applied to mature corn fields in the LRGV; one moth was recovered at Tilden, Texas, approximately 230 km downwind (Westbrook *et al* 1997b).

There is evidence that migration is a persistent process with wide-area dispersal characteristics. For example, low to moderate numbers of bollworms were captured in pheromone traps most nights near Agua Nueva, Texas, and other arid brushland locations more than 50 km downwind of the LRGV during peak emergence from mature corn in the LRGV (Westbrook *et al.* 1997b). Also, Hendricks *et al.* (1973) showed that many sterile *H. virescens* released in the LRGV were captured in the arid brushland approximately 50 to 100 km downwind of the LRGV. Adult H/H have been captured during the fall and mid-winter in light traps and pheromone traps on oil platforms 30 to 280 km from shore in the Gulf of Mexico (Sparks *et al.*1986; Keaster *et al.* 1996) and by direct capture aboard a ship (Wolf *et al.* 1986b). At first inspection, such flight habits would seem to ensure suicide of the migrants, but it is possible that individual migrants fly on multiple nights over land (Westbrook *et al.* 1995) and continuously over water (Wolf *et al.* 1986b) until finding suitable habitats. Westbrook *et al.* (1997a) reported dates when citrus pollen-marked bollworms were captured more than 100 km beyond the estimated maximum range of one-night flight (i.e., vector sum of wind velocity and insect flight velocity) from the nearest source of blooming citrus (i.e., the LRGV).

The capability of individual WSR-88D doppler weather radars (Crum and Alberty 1993) to detect the abundance and velocity of migrating H/H over large areas (10,000 km^2) is being investigated. Field studies using entomological radars and atmospheric sounding instrumentation have provided aerobiological data for direct comparison with simultaneous WSR-88D reflectivity and radial velocity data. Initial results were prepared using WSR-88D Level IV data which are stored at discrete data intervals for each radar range volume (i.e., 1 deg. azimuth x 1 deg. elevation x 1 km range) for graphical presentation. Radar reflectivity measures the amount of transmitted power that is returned to the radar after contact with atmospheric constituents such as precipitation, particulates, and

organisms including insects, bats, and birds. A positive log-linear regression ($r^2 = 0.92$) between the insect concentration measured by a scanning entomological radar and base reflectivity using WSR-88D Level IV data near New Braunfels, Texas, is shown in Fig. 1. It is important to keep in

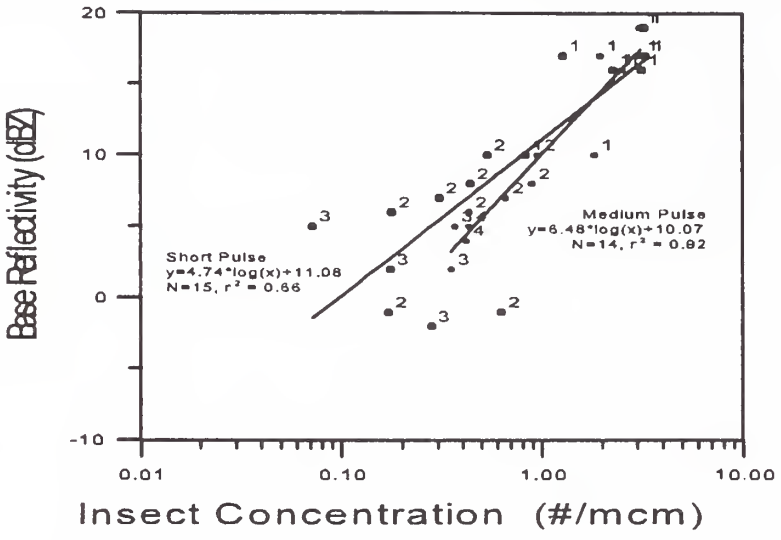

Fig. 1. WSR-88D radar reflectivity as a function of the aerial concentration of bollworm-size targets detected by an entomological scanning radar near New Braunfels, Texas, on 16 August 1996.

mind that the insect concentration data in Fig. 1 cover a range of only one order of magnitude, yet H/H concentration in the LRGV often spans five orders of magnitude (0.01 to 1000 insects per million cubic meters). Temporal patterns of base reflectivity at Moore Air Base, on the downwind perimeter of the LRGV, show striking similarity to patterns of insect concentration during peak emergence from mature corn. Base reflectivity at Moore Air Base increased from 0 dBZ at sunset to a maximum value of 11 dBZ at 0.5 to 1.5 h after sunset, then decreased linearly to 0 dBZ at sunrise (Fig. 2). Also, nightly mean reflectivity decreased steadily from 11 to 0 dBZ during the approximate latter half of the peak bollworm emergence from mature corn in the LRGV (2-11 June 1995) (Fig. 3). The radial component of wind velocity measured by radiosondes and pilot balloons showed a positive linear regression ($r^2 = 0.50$) with radar base radial velocity near New Braunfels (Fig. 4). Detailed analyses using WSR-88D Level II data are being reported in pending manuscripts (J.K. Westbrook, unpublished data).

Assessing Impacts of Movement and Migration

The actual impact of movement and migration on H/H infestations and pest management has not been well-documented. One of the major reasons for the elusiveness of an impact assessment is that it is very difficult to discriminate between migrant and locally-emerged moths. In fact, very few previous studies (Snow *et al.* 1969; Hendricks *et al.* 1973; Haile *et al.* 1975; Ramaswamy *et al.* 1985;

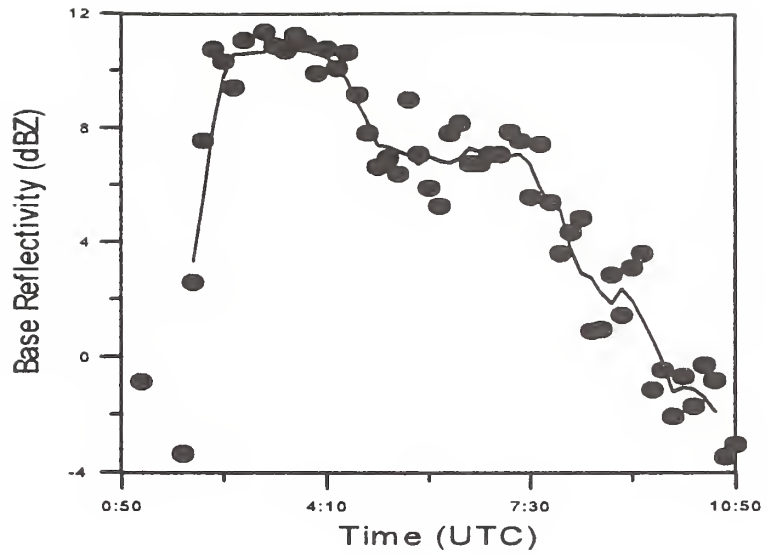

Fig. 2. Temporal pattern of nightly mean radar reflectivity (WSR-88D radar beam at 0.5 degrees elevation) near Moore Air Base (Mission), Texas, from 2-11 June 1995.

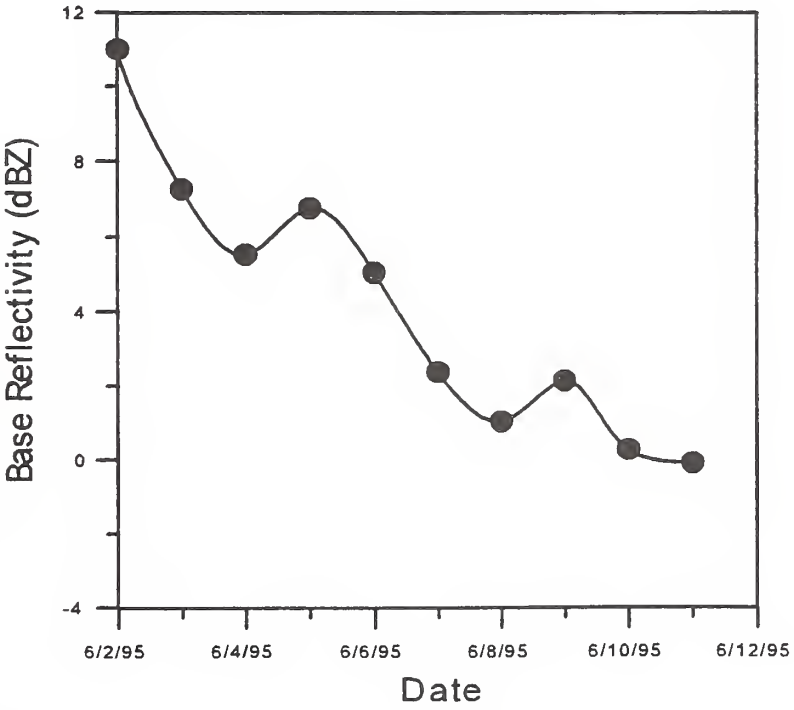

Fig. 3. Daily pattern of nocturnal mean reflectivity (WSR-88D radar beam at 0.5 degrees elevation) near Moore Air Base (Mission), Texas, from 2-11 June 1995.

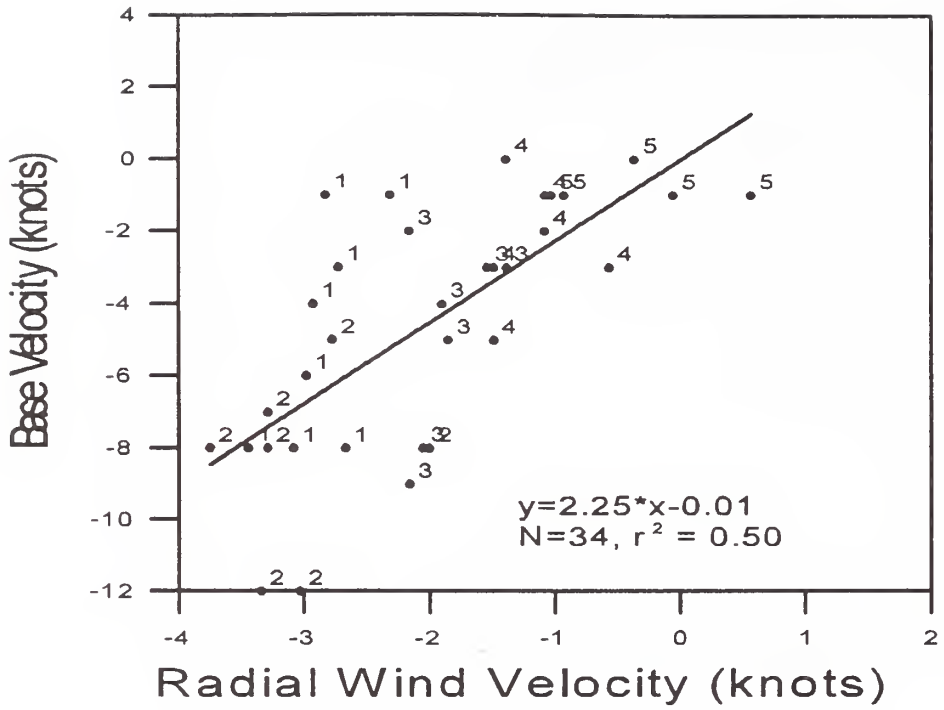

Fig. 4. WSR-88D radial velocity versus the radial component of wind speed near New Braunfels, Texas, 16 August 1996.

Schneider *et al.* 1989) have used marking methods to identify H/H migrants and determine their dispersal. The maximum dispersal range of (lab-reared) tobacco budworms reported from previous mark-capture studies was 113 km (Hendricks *et al.* 1973). The difficulty to determine abundance and movement has been exacerbated by inadequate sampling methods. Recent studies have shown that marked feral bollworms have been captured at the perimeter (greater than 600 km range) of large pest monitoring areas (Westbrook *et al.* 1997a; Westbrook *et al.* 1997b), and may have exited the areas in sufficient numbers to contribute to economic infestations. Efforts to identify migrants from locally-emerged H/H have focused on genetic differences (Narang *et al.* 1994), radioisotopes and trace elements, but new methods are still needed. Most previous research to discriminate between migrants and locally-emerged H/H has concentrated on the adult stage. Pollens and spores from plants which do not occur naturally in an area have been valuable in determining potential source areas of marked adult H/H based on host plant distribution and phenological stage. These biological markers should become much more significant to the study of H/H movement and migration as geographic information systems incorporate insect, host plant, climate, and other agricultural and environmental factors (Liebhold *et al.* 1993). Naturally-occurring stable isotopes, such as deuterium which was used to determine the geographic habitat areas of deer (Cormie et al. 1994), may help to identify the source regions of H/H on a continental scale. Miniature radar diode tags have been used to assess local movement of beetles (Mascanzoni and Wallin 1986), bees (Riley *et al.* 1996), and butterflies (Roland *et al.* 1996), but require further miniaturization for application to H/H research. DNA

analysis of guano and stomach contents of Mexican free-tailed bats (*Tadarida brasiliensis*), may reveal the degree of in-flight suppression of H/H and other nocturnal insects by predatory bats (McCracken 1996). Bat dietary analyses may also help describe the chronology, abundance and source areas of consumed nocturnal insect species in Mexico and the southern U.S.

Renewed collaborative efforts are needed to quantify the impact of migrants on pest infestations. Agronomic impacts can then be determined with respect to host plant availability, crop phenological stage, duration of migration events, level of insecticide resistance, and pest abundance. Several recent technologies may contribute to the success of pest management on farm-by-farm and areawide bases. Continuous surveillance by the NEXRAD national network of approximately 100 WSR-88D doppler weather radars may generate real-time estimates of the abundance and dispersal of H/H, other pests, and beneficial organisms over the continental U.S. Automatic vertical-looking entomological radars with target classification features and wind profilers could complement the network of WSR-88D doppler weather radars to enhance the spatiotemporal scope of the aerobiological information.

References

Callahan, P.S., A.N. Sparks, J.W. Snow, and W.W. Copeland. 1972. Corn earworm moth: vertical distribution in nocturnal flight. Environ. Entomol. 1: 497-503.

Cormie, A.B., H.P. Schwarcz, and J. Gray. 1994. Relation between hydrogen isotopic ratios of bone collagen and rain. Geochimica et Cosmochimica Acta 58: 377-391.

Crum, T.L. and R.L. Alberty. 1993. The WSR-88D and the WSR-88D Operational Support Facility. Bull. Amer. Meteorol. Soc. 74: 1669-1687.

Drake, V.A. 1993. Insect-monitoring radar: a new source of information for migration research and operational pest forecasting. pp. 452-455. In S.A. Corey, D.J. Dall, and W.M. Milne (eds.), Pest Control and Sustainable Agriculture. CSIRO Publications, Melbourne, Australia.

Farrow, R.A. and J.C. Daly. 1987. Long-range movements as an adaptive strategy in the genus *Heliothis* (Lepidoptera: Noctuidae): a review of its occurrence and detection in four pest species. Austral. J. Zool. 35: 1-24.

Fitt, G.P. 1989. The ecology of *Heliothis* species in relation to agroecosystems. Ann. Rev. Entomol. 34: 17-52.

Glick, P.A. and L.W. Noble. 1961. Airborne movement of the pink bollworm and other arthropods. U.S. Dept. of Agric., Techn. Bull. 1255. 20 pp.

Haile, D.G., J.W. Snow and J.R. Young. 1975. Movement by adult *Heliothis* released on St. Croix to other islands. Environ. Entomol. 4: 225-226.

Hartstack, A.W. J.D. Lopez, R.D. Muller, W.L. Sterling, E.G. King, J.A. Witz and A.C. Eversull. 1982. Evidence of long range migration of *Heliothis zea* (Boddie) into Texas and Arkansas. Southwest. Entomol. 7: 188-201.

Hayes, J.L. and M. Bell. 1994. Evaluation of early-season baculovirus treatment for suppression of *Heliothis virescens* and *Helicoverpa zea* (Lepidoptera: Noctuidae) over a wide area. J. Econ. Entomol. 87: 58-66.

Hendricks, D.E., H.M. Graham and J.R. Raulston. 1973. Dispersal of sterile tobacco budworms from release points in northeastern Mexico and southern Texas. Environ. Entomol. 2: 1085-1088.

Hendrix, W.H., III, T.F. Mueller, J.R. Phillips and O.K. Davis. 1987. Pollen as an indicator of long-distance movement of *Heliothis zea* (Lepidoptera: Noctuidae). Environ. Entomol. 16: 1148-1151.

Johnson, S.J. 1995. Insect migration in North America: synoptic-scale transport in a highly seasonal environment. pp. 31-66. In V.A. Drake and A.G. Gatehouse (eds.), Insect Migration: Tracking Resources Through Space and Time. Cambridge University Press, Cambridge, Great Britain.

Keaster, A.J. 1996. Noctuid moths and other insects captured in wing-style traps baited with black cutworm (Lepidoptera: Noctuidae) pheromone on offshore oil platforms in the Gulf of Mexico, 1988-1991. J. Kansas Entomol. Soc. 69: 17-25.

King, A.B.S. 1994. *Heliothis / Helicoverpa* (Lepidoptera: Noctuidae). *In* G.A. Matthews and J.P. Tunstall (eds.), Insect Pests of Cotton. pp. 39-106. CAB International, Wallingford, U.K.

Knipling, E.F. and E.A. Stadelbacher. 1983. The rationale for areawide management of *Heliothis* (Lepidoptera: Noctuidae) populations. Bull. Entomol. Soc. Am. 29: 29-37.

Liebhold, A.M., R.E. Rossi and W.P. Kemp. 1993. Geostatistics and geographic information systems in applied insect ecology. Ann. Rev. Entomol. 38: 303-327.

Lingren, P.D., and W.W. Wolf. 1982. Nocturnal activity of the tobacco budworm and other insects. pp. 211-228. *In* J.L. Hatfield and I.J. Thomason (eds.), Biometeorology in Integrated Pest Management. Academic Press, New York.

Lingren, P.D., V.M. Bryant, Jr., J.R. Raulston, M. Pendleton, J. Westbrook and G.D. Jones. 1993. Adult feeding host range and migratory activities of corn earworm, cabbage looper, and celery looper (Lepidoptera: Noctuidae) moths as evidenced by attached pollen. J. Econ. Entomol. 86: 1429-1439.

Lingren, P.D., J.K. Westbrook, V.M. Bryant, Jr., J.R. Raulston, J.F. Esquivel and G.D. Jones. 1994. Origin of corn earworm (Lepidoptera: Noctuidae) migrants as determined by *Citrus* pollen markers and synoptic weather systems. Environ. Entomol. 23: 562-570.

Lingren, P.D., J.R. Raulston, T.W. Popham, W.W. Wolf, P.S. Lingren, and J.F. Esquivel. 1995. Flight behavior of corn earworm (Lepidoptera: Noctuidae) moths under low wind speed conditions. Environ. Entomol. 24: 851-860.

Mascanzoni, D. and H. Wallin. 1986. The harmonic radar: a new method of tracing insects in the field. Ecol. Entomol. 11: 387-390.

McCracken, G.F. 1996. Bats Aloft: a study of high-altitude feeding. BATS 14: 7-10.

Narang, S. K., J. C. Carpenter, L. J. Heilmann, J. D. DeVault and J. D. Lopez, Jr. 1994. DNA fingerprinting of *Helicoverpa zea* populations: deciphering the source of migrants. In *1993 Supplement to the Five-Year National Research Action Plan for Development of Suppression Technologies,* eds. J. R. Raulston, J. R. Coppedge, R. M. Faust and P. D. Lingren, 252-272. Junction, TX, Nov. 8-11, 1993. U.S. Department of Agriculture, Agricultural Research Service, Washington, D.C.

Ramaswamy, S.B., R.T. Roush and W.F. Kitten. 1985. Release and recapture-probabilities of laboratory-adapted and wild-type *Heliothis virescens* (F.) (Lepidoptera: Noctuidae) in pheromone-baited traps. J. Entomol. Sci. 20: 460-464.

Raulston, J.R., S.D. Pair, J. Loera, A.N. Sparks, W.W. Wolf, J.K. Westbrook, G.P. Fitt and C.E. Rogers. 1992. *Helicoverpa zea* (Lepidoptera: Noctuidae) pupa production in fruiting corn in northeast Mexico and south Texas. Environ. Entomol. 21: 1393-1397.

Raulston, J.R. and J.E. Slosser (eds.). 1995. *Noctuids: Recent Advances in Detection and Migration in the United States*, Supplement No. 18, Southwest. Entomol.

Riley, J.R., A.D. Smith, D.R. Reynolds, A.S. Edwards, J.L. Osborne, I.H. Williams, N.L. Carreck, G.M. Poppy. 1996. Tracking bees with harmonic radar. Nature 379: 29-30.

Reynolds, D.R., J.R. Riley, N.J. Armes, R.J. Cooter, M.R. Tucker, and J. Colvin. 1997. Techniques for quantifying insect migration. D.R. Dent and M.P. Walton (eds.), Methods in Ecological and Agricultural Entomology. pp. 111-145. CAB International, Wallingford, U.K.

Roland, J., G. McKinnon, C. Backhouse,and P.D. Taylor. 1996. Even smaller radar tags on insects. Nature 381: 120.

Schneider, J.C., R.T. Roush, W.F. Kitten and M.L. Laster. 1989. Movement of *Heliothis virescens* (Lepidoptera: Noctuidae) in Mississippi in the spring: implications for area-wide management. Environ. Entomol. 18: 438-446.

Smith, A.D., J.R. Riley and R.D. Gregory. 1993. A method for routine monitoring of the aerial migration of insects by using a vertical-looking radar. Phil. Trans. R. Soc. Lond. B 340: 393-404.

Snow, J.W., W.W. Cantelo and M.C. Bowman. 1969. Distribution of corn earworm on St. Croix, U.S. Virgin Islands, and its relation to suppression programs. J. Econ. Entomol. 62: 606-611.

Sparks, A.N., R.D. Jackson, J.E. Carpenter, and R.A. Muller. 1986. Insects captured in light traps in the Gulf of Mexico. Ann. Entomol. Soc. Amer. 79: 132-139.

Westbrook, J.K., C.T. Allen, F.W. Plapp, Jr. and W. Multer. 1990. Atmospheric transport and pyrethroid-resistant tobacco budworm, *Heliothis virescens* (Lepidoptera: Noctuidae), in western Texas in 1985. J. Agric. Entomol. 7: 91-101.

Westbrook, J. K., P. D. Lingren, W. W. Wolf and J. R. Raulston. 1994. New Concepts in Migration Research. In: *Heliothis/Helicoverpa*: *1993 Supplement to the Five-Year National Research Action Plan for Development of Suppression Technologies, First Annual Review,* eds. J. R. Raulston, J. R. Coppedge, R. M. Faust and P. D. Lingren, 214-233. Junction, TX, Nov. 8-11, 1993. U.S. Department of Agriculture, Agricultural Research Service, Washington, D.C.

Westbrook, J. K., W. W. Wolf, P. D. Lingren and J. R. Raulston. 1994. Tracking tetroons to evaluate tobacco budworm and bollworm migration. In *Proc. Beltwide Cotton Conf.*, 791-793. San Diego, CA., Jan. 5, 1994. National Cotton Council of America, Memphis, TN.

Westbrook, J.K., R.S. Eyster, W.W. Wolf, P.D. Lingren, and J.R. Raulston. 1995. Migration pathways of corn earworm (Lepidoptera: Noctuidae) indicated by tetroon trajectories. Agric. and Forest Meteorology 73: 67-87.

Westbrook, J. K., J. R. Raulston, W. W. Wolf, S. D. Pair, R. S. Eyster and P. D. Lingren. 1995. Field observations and simulations of atmospheric transport of noctuids from northeastern Mexico and the south-central U.S. In *Noctuids: Recent Advances in Detection and Migration in the U.S.*, eds. J. R. Raulston and J. E. Slosser, 25-44. Supplement No. 18, Southwest. Entomol.

Westbrook, J.K., W.W. Wolf, P.D. Lingren, J.R. Raulston, J.D. Lopez, Jr., J.H. Matis, R.S. Eyster, J.F. Esquivel, and P.G. Schleider. 1997a. Early-season migratory flights of corn earworm (Lepidoptera: Noctuidae). Environ. Entomol. 26: 12-20.

Westbrook, J.K., J.F. Esquivel, J.D. Lopez, Jr., G.D. Jones, W.W. Wolf, and J.R. Raulston. 1997b. Validation of bollworm migration across south-central Texas in 1994-1996. In *Proc. 1997 Beltwide Cotton Conf.* 2: 936-940.

Wolf, W.W., J.K. Westbrook and A.N. Sparks. 1986a. Relationship between radar entomological measurements and atmospheric structure in south Texas during March and April 1982, pp. 84-97. In A.N. Sparks [Ed.], Long-Range Migration of Moths of Agronomic Importance to the United States and Canada: Specific Examples of Occurrence and Synoptic Weather Patterns Conducive to Migration. USDA-ARS-43.

Wolf, W.W., A.N. Sparks, S.D. Pair, J.K. Westbrook and F.M. Truesdale. 1986b. Radar observations and collections of insects in the Gulf of Mexico. pp. 221-234. In W. Danthanarayana [Ed.], *Insect Flight: Dispersal and Migration*. Springer-Verlag, Berlin.

Wolf, W.W., J.K. Westbrook, J. Raulston, S.D. Pair, and S.E. Hobbs. 1990. Recent airborne radar observations of migrant pests in the United States. Phil. Trans. Royal Soc. London B 328: 619-630.

Wolf, W.W., C.R. Vaughn, R. Harris and G.M. Loper. 1993. Insect radar cross-sections for aerial density measurements and target classification. Trans. Am. Soc. Agric. Engrs. 36: 949-954.

Wolf, W. W., J. K. Westbrook, J. R. Raulston, S. D. Pair and P. D. Lingren. 1993. Radar detection of ascent of *Helicoverpa zea* (Lepidoptera:Noctuidae) moths from corn in the Lower Rio Grande Valley of Texas. In *Proc. 13th International Congress of Biometeorology.* Calgary, Canada, Sept. 12-18, 1993.

Wolf, W. W., J. K. Westbrook, J. R. Raulston, S. D. Pair and P. D. Lingren. 1995. Radar observations of orientation of noctuids migrating from corn fields in the Lower Rio Grande Valley. In *Noctuids: Recent Advances in Detection and Migration in the United States*, eds. J. R. Raulston and J. E. Slosser, 45-62. Supplement No. 18, Southwest. Entomol.

THE USE OF SELECTIVE CHEMICALS IN THE MANAGEMENT OF *HELIOTHIS/HELICOVERPA*

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ABSTRACT

Newer chemical insecticides with novel modes of action are discussed with reference to cotton insect pest management, emphasizing selectivity for pests and beneficial arthropods. Included are chemicals which are targeted particularly at lepidopterans, with emphasis on Heliothines. In addition, recent data on the selectivity of currently registered cotton insecticides are presented. At the present time, a number of novel insecticides are available, or are expected to be registered for use in the near future. Thus, an array of new tools will be available for use in IPM in cotton and other crops.

INTRODUCTION

Not since the late 1970's, when the UV-stable pyrethroid insecticides were introduced, have we been in the position of having available a variety of new chemical insecticides for use against important pests in agriculture. This event is particularly important in the case of lepidopterous pests, and especially for the Heliothines, which, in many parts of the world, are resistant to several classes of insecticides available for their control. For example, populations of the tobacco budworm, *Heliothis virescens* (F.), in the mid-South have developed resistance to pyrethroid, carbamate, organophosphorus, and cyclodiene insecticides (Elzen et al. 1990, 1992, 1994a, b; Martin et al. 1995). Furthermore, the budworm/bollworm complex was the number one pest in U.S. cotton in 1996 with an average yield reduction of 2.37% (Hardee and Herzog 1997). In Australia, the cotton bollworm, *Helicoverpa armigera* (Hubner) is most noted for current resistance to pyrethroids and the cyclodiene endosulfan (Gunning et al. 1984, Gunning and Easton 1994, Gunning et al. 1995). In addition, *H. armigera* have become resistant to pyrethroids in Thailand, Turkey, Indonesia, and India (Ahmad and McCaffery 1991), and to pyrethroid and organophosphorus insecticides in China (Wu et al. 1997) . Several representatives of these new insecticides are more specifically targeted at other pests with current or potential resistance, including aphids, whiteflies, and *Lygus* spp.

The introduction of these compounds as new crop protection chemicals increases the potential for managing resistance via chemical rotations and introduces new opportunities for integrated pest management (IPM) programs. Most of these new products have novel modes of action and few predictions of cross-resistance with present insecticides have been made. In many cases, these new products have the potential for providing a short-term solution to many serious pest outbreaks. In addition, there have been many claims concerning the selectivity of these products to beneficial arthropods.

Herein, we examine some of these new chemistries and current data with regard to potential selectivity, emphasizing reports on those new chemicals specifically targeted toward Heliothines. In addition, a recent examination of the selectivity of currently registered and newer insecticides on

predatory insects is summarized. Prospects for integrating these insecticides into IPM programs are discussed.

Newer Insecticides. The experimental insecticide fipronil (Regent) (Rhone-Poulenc Ag. Co.), a phenylpyrazole, represents a new class of chemicals with herbicidal and insecticidal properties (Klis et al. 1991a). Fipronyl, 1-[2,5-dicloro-4-trifluormethyl)-1H-pyrazole, has the substituents 3-cyano-4-[trifluoromethyl)sulfinyl]-5-amino. Other fiprole pesticidal compounds with other heterocyclic substituents also exist. The insecticidal phenylpyrazoles produce symptoms indicative of direct action on the nervous system. They appear to be potent antagonists of the GABA-activated chloride channels in insects. Symptoms of poisoning are similar to those of the pyrethroids (Klis et al. 1991b, Cole et al. 1993).

Fipronil is active on piercing and sucking insects and has been widely tested in Europe and South America as a foliar spray, soil applied insecticide, seed treatment, and in baits (Colliot et al. 1992). Insecticidal activity is expressed via contact and ingestion. In contrast to other new insecticides discussed herein, fipronil also appears to be effective against spider mites (Moffat 1993). Fipronil is effective against a broad range of insect pests on various crops, including cotton, rice, sugarcane, bananas, potatoes, maize, sugar beet, and sunflower. Fipronil is effective against thrips, tarnished plant bugs, and the boll weevil on cotton. Good activity has also been shown against leafworms, bollworms, and budworms. Favorable selective toxicity between insects and mammals could lead to further development of highly active insecticidal compounds of this class. Furthermore, because of their novel mode of action, phenylpyrazoles could be useful in controlling pests which are resistant to currently used insecticides.

Burris et al. (1994) examined the efficacy of fipronil in Louisiana and Mississippi. They found that adult thrips were suppressed by fipronil in-furrow treatments and that control was comparable or better than that obtained with aldicarb and acephate standards. Foliar treatments of fipronil at 0.05 lb(AI)/acre proivided 60% control of adult thrips and was comparable to acephate in-furrow treatment. Immature thrips were controlled by fipronil in-furrow treatments at 0.1 and 0.15 lb(Ai)/acre with results equal to or better than acephate at 0.9 lb(AI)/acre. Fipronil applied as a foliar treatment for thrips control was as effective as acephate when used at higher rates.

While aphid control was variable, and only suppression was indicated, Burris et al. (1994) found that fipronil reduced boll weevil damage better than or equal to a standard azinphos methyl treatment. Dose-mortality studies indicated that fipronil is extremely toxic to the boll weevil. Further, no cross-resistance with other chemicals was found. Considerably less active ingredient was required per application of fipronil compared with other standard insecticides.

The efficacy of fipronil for *Lygus lineolaris* (Palisot de Beauvois) was found to be excellent (Burris et al. 1994), spray chamber data indicated that fipronil was comparable to dimethoate at equivalent ratres. These data were also confirmed in field trials. Fipronil may provide enhanced control of resistant insects and be effective in a program designed to delay the development of resistance. The tarnished plant bug has developed resistance to many of the insecticides currently used for its control (Snodgrass 1994, 1996). In addition, in one of the few reports available, fipronil was least toxic to *Hippodamia convergens* Guerin-Meneville of seven insecticides, including carbamate, pyrethroid, and organophosphorus compounds, applied topically (Kaakeh et al. 1996).

The data indicate that fipronil may be an effective alternative where resistance poses a threat. In-furrow treatments of fipronil could be an alternative to currently used materials and provide control of multiple pest species, thus possibly eliminating the need for additional foliar sprays. In

addition to providing reduced environmental impact in this use pattern, it requires less active ingredient for comparable control with other insecticides.

Imidacloprid, 1-[(6-chloro-3-pyridinyl)methyl]-N-nitro-2-imidazolidinimine), is a chloronicotinyl analogue of nitromethylene insecticidal compounds. It has been developed worldwide by Bayer AG (Anonymous 1990). It is marketed under the trade names of Admire, Provado, Marathon, Merit, and Gaucho (seed treatment).

The nitromethylene class of insecticides comprises a group of broad spectrum chemicals with systemic activity. Preliminary studies suggest that imidacloprid has a novel mode of action which has been previously encountered with the insecticide cartap. These compounds interact at a nicotinic acetycholine receptor binding site (Tomizawa and Yamamoto 1992).

Imidacloprid is a systemic and contact insecticide of low mammalian toxicity which may be used in a broad range of important crops. Primary activity is on sucking insects such as aphids, leafhoppers, thrips, and whiteflies, including strains resistant to conventional insecticides. It is also effective against coleopterans, dipterans, and some lepidopterans (Mullins 1993). The silverleaf whitefly, *Bemesia argentifolii* Bellows and Perring, is resistant to many of the insecticides available for control; imidacloprid has the potential to prevent or delay economic disasters in vegetables and cotton due to resistant populations of the whitefly. Imidacloprid has also shown activity on aphids, whiteflies, thrips, and plant bugs in cotton (Almand and Mullins 1991, Mullins and Engle 1993). Recently, imidacloprid was found to have ovicidal and larvacidal activity on *H. virescens* (Elzen 1997). Thus, beneficial effects from imidacloprid application to control other insects could be possible in the case of the coincidental presence of *H. virescens* at low levels .

Most likely due to its novel mode of action, no cross-resistance with any resistant species has been detected via oral ingestion of imidacloprid in field and laboratory testing. In addition, systemic activity and good residual action makes this insecticide appropriate for seed treatment and soil application. Effective, persistent early season control is shown in crops such as cereals, corn, cotton, potatoes, rice, sorghum, and vegetables. Late season pests can be controlled by foliar applications (Elbert et al. 1991).

The effectiveness of imidacloprid on the tarnished plant bug was recently evaluated on cotton in a spray chamber (Elzen 1993) and in a replicated field trial (Elzen and Snodgrass 1994). Imidacloprid was equivalent to methamidophos for control of tarnished plant bugs in the spray chamber and comparable to dimethoate and methamidophos for control of tarnished plant bug nymphs in the field.

Imidacloprid has no effect on nematodes or spider mites (Elbert et al. 1991). It also has little impact on predatory mites at foliar rates effective against phytophagous insects. However, at similar concentrations, imidacloprid was toxic to several predatory insects including *Geocoris punctipes* (Say) and *H. convergens*, which are major predators of aphids (Mizell and Sconyers 1992). Imidacloprid was also the most toxic insecticide tested on *H. convergens* (Kaakeh et al. 1996).

Imidacloprid is reportedly non-toxic to bees (Elbert et al. 1991). At high rates, it does not impair activity of soil microbes and other fauna. Field rates are not harmful to fish, but show some acute toxicity to birds. Mammalian toxicity is low and there appears to be repellency to birds and mammals (Pfluger and Schmuck 1991).

Systemic properties and long residual activity are often considered advantageous with respect to need for frequent treatments. However, the persistence of imidacloprid could be detrimental to insecticide resistance management stratregies. Persistent pesticides provide intense selection pressure and may enhance the development of resistance (Roush and Daly 1990).

The American Cyanamid Co. has developed a new class of insecticides based on the natural product dioxapyrrolomycin which was first reported in 1987, following discovery of insecticidal activity of a fermentation broth from a Streptomyces strain. A new series of insecticidal pyrroles with high insecticidal activity and low mammalian toxicity, was subsequently developed. One compound from this series, AC 303,630, [4-bromo-2-(4-chlorophenyl)-1-(ethoxy-methyl)-5-(trifluoromethyl)pyrrole-3-carbonitrile], chlorfenapyr, is currently in development by American Cyanamid as a broad spectrum insecticide/miticide with the name Pirate (Kuhn et al. 1993).

The proposed mode of action of the insecticidal pyrroles is related to the uncoupling of oxidative phosphorylation (Kuhn et al. 1993). Thus, they are not nerve poisons but function by inhibiting energy production in the mitochondria (Moffat 1993). The potentially non-selective mode of action of the pyrroles was overcome by synthesis, creating a pro-insecticide, namely AC 303,630 (Kuhn et al. 1993). The pro-insecticide is activated by oxidases in insects, but is not readily converted in mammals and is readily excreted (Moffat 1993). The compound, however, is acutely toxic to birds and some aquatic organisms. If applied properly, these possible ecotoxicological problems could be avoided.

Pirate is active through foliar application as well as by systemic uptake through roots in a hydroponic system. It shows both contact and stomach activity, and moderate residual activity on plants. It has been shown to be effective as an acaricide and larvicide of lepidopterans (Lovell et al. 1991).

In tests with *H. virescens*, Pirate was significantly more toxic to larvae by ingestion than by contact. Laboratory tests indicated no cross-resistance to pyrethroid resistant *H. virescens* (Treacy et al. 1991). It has been reported that the use of Pirate for suppression of *Heliothis* spp. also provided suppression of the boll weevil (Farlow et al. 1992). Development of Pirate for control of lepidopterous pests of cotton could be very valuable, given the high levels of resistance to all classes of insecticides in *H. virescens* (Elzen et al. 1992) and the possible development of resistance in the boll weevil (Kanga et al. 1995). Recently, Pimprale et al. (1997) found that chlorfenapyr was significantly more toxic to pyrethroid resistant larvae of *H. virescens* than to pyrethroid susceptible larvae, and that it was generally as effective as currently registered insecticides.

Pirate was also shown to provide acceptable control of cabbage looper (*Trichoplusia ni* Hubner), soybean looper (*Pseudoplusia includens* Walker), cotton leaf perforator (*Bacculatrix thurberiella*), *Tetranychus urticae* Koch , and thrips spp. (Farlow et al. 1992). Pirate also had high activity against beet armyworm (*Spodoptera exigua* Hubner) (Farlow et al. 1992, Whitehead et al. 1993). More recently, the effect of several insecticides, including Pirate, was evaluated on *S. exigua* (Elzen 1996). In these spray chamber tests, Pirate provided 100 percent control of third instar beet armyworms, and was significantly more effective in comparison with other insecticides. It would appear that a primary focus for Pirate might be the beet armyworm problem which often surfaces in cotton in the Southeast and mid-South of the U.S. This pest is tolerant to most insecticides currently used for its control. An insecticide that would control these populations and provide suppression of other pests, such as spider mites and the boll weevil, would be desirable. However, Pirate is not innocuous to beneficial insects. Pirate was rated as slightly harmful (25-50% mortality) to the insidious flower bug, *Orius insidiosus* (Say) and *Cotesia plutella*, in laboratory tests (Pietrantonio and Benedict 1997).

Another product with activity on lepidopterans has been recently developed by DowElanco. Produced by the soil actinomycete *Saccharopolyspora spinosa*, spinosad is a naturally occurring

mixture of two active components, 85% spinosyn A and 15% spinosyn D. Structurally, these compounds are macrolides. Spinosins cause widespread excitation of neurons in the central nervous system, leading to involuntary muscle contractions and tremors. The excitation was found to be due to persistent activation of nicotinic acetylcholine receptors and prolongation of acetylcholine responses by a novel mechanism that distinguishes spinosad from all other nicotinic agonists. Thus, spinosad has a novel mode of action and no cross-resistance is expected (Salgado et al. 1997). It has both contact and stomach activity and rapid knockdown, and has a broad spectrum for lepidopterans including eggs when directly sprayed and larval stages up to the third stadia. It has little or no activity against predacious insects or sucking pests (Thompson et al. 1996a). This product has recently received registration and is marketed as Tracer by DowElanco. In tests reported by DowElanco in 1995, Tracer at 50 to 100 g (AI)/ha was equal to or greater than commercial standards in small plots for control of *H. virescens* (Huckaba et al. 1996). Murray and Lloyd (1997) reported that Tracer was not disruptive to predator populations in Australian cotton and suggested that the product has an important role in integrated pest management programs. Hendrix et al. (1997) reported that Tracer was softer on beneficials than Pirate, Decis, Karate, and Orthene. Pietrantonio and Benedict (1997) rated Tracer as harmless (causing <25% mortality) to *O. insidiosus* and *C. plutella* in laboratory studies.

Tracer is recommended for control of *H. virescens, H. zea, S. exiqua,* fall armyworm (*S. frugiperda*), *P. includens*, *T. ni*, *B. thurberiella*, and saltmarsh caterpillar (*Estigmene acrea* Drury) (Thompson et al. 1996b).

The broad spectrum lepidoptericide, Proclaim (emamectin benzoate), is a second generation avermectin under development by Merck & Co. (Dunbar et al. 1996). Avermectins are a family of macrocyclic lactones produced by the soil microorganism *Streptomyces avermitilis*. Isolation of the crude fermentation product of *S. avermitilis* yielded a family of eight closely related avermectin homologues, of which avermectins B1 (a and b) were the major components. Further synthesis yielded emamectin benzoate which is highly effective against a broad range of lepidopteran larvae and other insects. It is most effective through ingestion but also has contact activity. Through translaminar movement, this product penetrates the plant cuticle, thus providing long residual activity. Research trials indicate that emamectin benzoate is effective at very low use rates and is not disruputive to beneficial arthropods. Its activity has been shown on beet armyworm, loopers, bollworm, tobacco budworm and other lepidopterans (White et al. 1997). Concentration-mortality studies showed emamectin benzoate to be more toxic to *H. virescens*, *T. ni*, and *S. exiqua* than chlorfenapyr (Pirate) (Dunbar et al. 1996).

Emamectin benzoate affects arthropods by potentiating glutamate and gamma-amino butyric acid to stimulate an influx of chloride ions into nerve cells, resulting in loss of cell function and disruption of nerve impulses. Shortly after exposure, larvae stop feeding and become paralyzed irreversibly. Maximum mortality occurs by three to four days (White et al. 1997).

DPX-MP062 [Indeno [1,2-e] [1,3,4]oxadiazine-4a (3H)-carboxylic acid, 7-chloro-2,5-dihydro-2-[[(methoxycarbonyl) [(4-trifluoromethoxy) phenyl] amino] carbonyl]-, methyl ester], an insecticidal dihydropyrazole, is a new compound with broad spectrum control of lepidopterans developed by DuPont Agricultural Products. DPX-MP062 has a novel mode of action which results in blockage of sodium channels in nerve cells. In addition to paralysis and death, insect behavior is altered following exposure, resulting in rapid cessation of feeding. This material acts via both contact and ingestion. Laboratory and field studies have shown no cross resistance. DPX-MP062 is effective against *Heliothis, Helicoverpa, Spodoptera, Plutella, Trichoplusia, Lobesia, Cydia* and other

lepidopteran pests in cotton, vegetables, and fruit, while preserving beneficial insects and mites (Harder et al. 1997.).

Two juvenoids, fenoxycarb and pyriproxyfen, are the first juvenoids to find a niche in crop protection due to stability in sunlight. Fenoxycarb (Ciba) is currently available in various formulations, notable as Logic and Award for the control of ants. Logic is the agricultural use trademark and can only be used in nonbearing citrus, fallow farm land, around farm buildings, airports, etc. Award is the trademark for use in home lawns, parks, playgrounds, ornamental nurseries, and similar situations. Pyriproxyfen is in development by Sumitomo Chemical Company (Miyamoto et al. 1993), and is currently marketed as Knack (Valent USA Corp.).

These juvenoids interfere with metamorphosis, reproduction, embryogenesis, and diapause. The stage controlled depends to a large extent on the target species (Miyamoto et al. 1993). The juvenoids are highly selective to target insects based on their mode of action.

Fenoxycarb, ethyl[2-(phenoxyphenoxy)ethyl]carbamate, disrupts the following transformations: 1) from egg to larvae (lepidopterans, fleas, ants); 2) from larvae to pupae (lepidopterans, fleas, ants (from late nymphs to adults in cockroaches); 3) from crawler to sessile insect (scale insects). Fenoxycarb is also effective against mosquitoes (Miyamoto et al. 1993) and a number of insects attacking fruit trees, vines, and stored products (Menn and Henrick 1985, Hull et al. 1991).

Fenoxycarb acts by contact and ingestion. It has translaminar activity in plants but is not translocated in the vascular system. Fenoxycarb has very low toxicity to birds and mammals.

Pyriproxyfen, 2-[1-methyl-2-(4-phenoxyphenoxy)ethoxy]pyridine, which is active against many species of mosquitoes and the housefly, was first registered in Japan in 1991. Pyriproxyfen is reported to be active on the green peach aphid *Myzus persicae* (Sulzer), arrowhead scale, greenhouse whitefly *Trialeurodes vaporariorum* (Westwood), tea scale *Fiorinia theae* Green, and pear psylla and its predators.

Juvenoids vary in activity and timing is extremely critical depending on target species. Timing for ovicidal activity is especially important. In developing JHAs, considerable effort must be spent in determining the most efficacious use patterns. Often, multiple applications are required, since, by their nature, these compounds are indirect toxicants and slower acting.

Juvenoids are generally favorably selective for non-target insects, however the effects on crustaceans needs further evaluation. Environmental studies indicate that enviromental persistence is transient, and they are safer to non-target vertebrates than conventional insecticides.

Wing et al. (1988) reported the discovery of the first insecticidal, non-steroidal agonist of ecdysone, RH-5849, 1,2-dibenzoyl-1-tert-butlyhydrazine. When injected into larvae of *Manduca sexta* (L.), RH-5849 was 50 times more active than the native moulting hormone in initiating premature moulting. In larval diets it was 670 times more active than 20-hydroxyecysone (J. A. Svoboda, pers. comm.). Structure activity optimization research in the Rohm and Haas laboratories yielded a superior field candidate RH-5992, 3,5-dimethlbenzoic acid 1-(1,1-dimethylethyl)-2-(4-ethylbenzoyl) hydrazine. This compound is undergoing extensive field evaluation world-wide, primarily targeted for control of lepidopterous larvae in deciduous fruit tree, vines and forestry. This material controls lepidopterous larvae by initiating a premature lethal molt which initiates within hours of ingestion of treated foliage. This premature molt results in immediate cessation of feeding. Actual death of larvae takes several days to occur. At typical use rates it has practically no activity against other orders of insects. In fact, Confirm was rated as harmless (causing <25% mortality) to *O. insidiosus* and *C. plutella* in the laboratory (Pietrantonio and Benedict 1997). Its selectivity for

lepidopterans and favorable toxicological and environmental profile make it a highly promising candidate insecticide in IPM programs (Heller and Mattioda 1992). This product is currently marketed as Confirm by Rohm and Haas and has received various emergency exemptions for use in cotton to control *S. exigua*.

An additional insect growth regulator, buprofezin, inhibits chitin biosynthesis and is under development by AgrEvo, marketed as Applaud. This product has recently received a section 18 emergency exemption for control of whiteflies. It is effective against nymphal stages of whitefly and is not disruptive of beneficial insects and mites.

Pymetrozine, CGA-215944, 1,2,4-Triazin-3(2H)-one,4,5-dihydro-5-methyl-4[(3 pyridinylmethylene)amino], represents a new class of insecticide (pyridine azomethine) which was discovered by Ciba Crop Protection. Pymetrozine is selectively active against homopterous insects. It is active against both immature and adult stages of whiteflies and has contact and systemic activity. Pymetrozine has a novel mode of action; it is known to interfere with feeding through inhibition of the salivary pump mechanism. Although insects remain alive on treated plants for 2 to 4 days, feeding stops soon after application and the change in behavior is irreversible. This product is being developed worldwide by Novartis for control of aphids and whiteflies in vegetables, ornamentals, field crops, hops, deciduous fruits and citrus, and brown planthopper in rice. The compound has low acute toxicity to mammals, terrestrial and aquatic wildlife, and very favorable environmental and toxicological properties (Ngo 1995). Proposed names for this new product are Sterling and Fulfill.

Conventional and Newer Insecticides: Case Study. Elzen et al. (unpublished) recently tested various insecticides on four species of beneficial insects, namely *O. insidiosus*, *G. punctipes*, *H. convergens*, and the green lacewing, *Chrysoperla carnea* (Stephens). Ten chemicals were tested at field rates using a spray chamber bioassay; these were Phaser (endosulfan), Guthion (azinphos methyl), malathion (ULV), Curacron (profenofos), Baythroid (cyfluthrin), Vydate (oxamyl), Provado, Regent, Pirate, and Tracer.

For *O. insidiosus*, Tracer, Guthion, and Provado were least toxic, producing 10.0, 0.0, and 10.0% mortality, respectively 72-h post-treatment. Malathion (80.0%) and Curacron (73.3%) were most toxic, with Baythroid, Vydate, Regent, Pirate, and Phaser causing intermediate mortality.

For *G. punctipes*, there was no mortality following treatment with Baythroid, Tracer, Vydate, Phaser, Curacron, or Guthion, and only 6.7% mortality following treatment with Provado. Regent was most toxic (86.7%); Pirate and malathion caused intermediate mortality.

For *H. convergens*, no mortality resulted from treatment with Vydate or Tracer and only 6.6% and 3.3% mortality after treatment with Regent and Pirate, respectively. Baythroid, Guthion, and malathion were most toxic at 93.0% mortality each. Provado, Phaser, and Curacron produced intermediate mortality.

For *C. carnea*, most materials tested were highly toxic with the exception of Baythroid (36.7%) and Tracer (23.3%).

Thus, there was considerable variability in response of the four species to the insecticides tested. However, Tracer was consistently least toxic to the species tested.

SUMMARY

With the exception of imidacloprid, which has some activity on *H. viriescens*, many of the insecticides discussed above do not have any particularly important activity on lepidopterans. This does not rule out their important role in systems where lepidopterous pests are a concern, or their

importance as insecticides with novel modes of action. However, Pirate, Tracer, Proclaim, DPX-MP062, and Confirm have been shown to have novel modes of action on lepidopterans and are important with regard to control of insecticide resistant pests. In addition, Tracer, Confirm, and possibly Pirate and DPX-MP062, have shown favorable selectivity for some beneficial insects. Thus, an array of new tools is currently being developed for use in IPM in cotton and other crops. However, studies of the selectivity of new insecticides should be continued.

This discussion of new insecticides with diverse chemical structures, different modes of action and insect control spectra provides evidence that the agrochemical industry is conducting intensive research in developing compounds that harmonize with the environment and that provide the means to develop more effective strategies to combat the ever present threat of resistance, through chemical diversity.

LITERATURE CITED

Ahmad, M. and A. R. McCaffery. 1991. Elucidation of detoxication mechanisms involved in resistance to insecticides in the third instar larvae of a field-selected strain of *Helicoverpa armigera* with the use of synergists. Pestic. Biochem. Physiol. 41: 41-52.

Almand, L. K., and J. W. Mullins. 1991. NTN 33893: A new insecticide for thrips/aphid/whitefly control, pp. 80-81. *In* Proc. Beltwide Cotton prod. Res. Conf. National Cotton Council, Memphis, TN.

Anonymous. 1990. Bay NTN 33893 technical and safety information sheets. Mobay Corporation Agricultural Chemicals Division. Kansas City, MO 64120.

Burris, E., B. R. Leonard, S H. Martin, C. A. White, J. B. Graves, R. Shaw, and W. P. Scott. 1994. Fipronil: Evaluation of soil and foliar treatments for control of thrips, aphids, plant bugs, and boll weevils, pp. 838-844. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Cole, L. M., R. A. Nicholson, and J. E. Casida. 1993. Action of phenylpyrazole insecticides at the GABA-gated chlorine channel. Pestic. Biochem. Physiol. 39: 47-54.

Colliot, F., K. A. Kukorowski., D. Hawkins, and D. A. Roberts. 1992. Fipronil: A new soil and foliar broad spectrum insecticide, pp. 29-34. *In* Brighton Crop Protection Conference--Pests and Diseases, Vol. I. The British Crop Protection Council, Surrey, UK.

Dunbar, D. M., R. D. Brown, J. A. Norton, and R. A. Dybas. 1996. Proclaim: A new insecticide for use on cotton, pp. 756-758. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Elbert, A., B. Becker, J. Hartwig, and C. Erdelen. 1991. Imidacloprid - a new systemic insecticide. Pflanzenshutz-Nachrichten Bayer. 44: 113-136.

Elzen, G. W. 1993. Evaluation of insecticides for control of tarnished plant bug, 1992. Insecticide & Acaricide Tests. 18: 366.

Elzen, G. W. 1996. Evaluation of beet armyworm (Lepidoptera: Noctuidae) tolerance to insecticides and response to IGR's. Southwest. Entomol. 21: 127-133.

Elzen, G. W. 1997. Changes in resistance to insecticides in tobacco budworm populations in Mississippi, 1993-1995. Southwest. Entomol. 22: 61-72.

Elzen, G. W., G. L. Snodgrass. 1994. Control of tarnished plant bug, 1993. Arthropod ManagementTests. 19: 222.

Elzen, G. W., P. J. O'Brien, and G. L. Snodgrass. 1990. Toxicity of various classes of insecticides to pyrethroid resistant *Heliothis virescens* larvae. Southwest. Entomol. 15: 33-38.

Elzen, G. W., S. H. Martin, J. B. Graves, and B. R. Leonard. 1994a. Resistance within classes of insecticides in tobacco budworm, pp. 764-768. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Elzen, G. W., S. Martin, B. R. Leonard, and J. B. Graves. 1994b. Inheritance, stability, and reversion of insecticide resistance in tobacco budworm (Lepidoptera: Noctuidae) field populations. J. Econ. Entomol. 87: 551-558.

Elzen, G. W., B. R. Leonard, J. B. Graves, E. Burris, and S. Micinski. 1992. Resistance to pyrethroid, carbamate, and organophosphate insecticides in field populations of tobacco budworm (Lepidoptera: Noctuidae) in 1990. J. Econ. Entomol. 85: 2064-2072.

Farlow, R. A., G. Goddard, R. Kepner, K. Umeda, and J. R. Whitehead. 1992. Efficacy of Pirate insecticide-miticide against insect and mite pests of U. S. cotton, pp. 877-880. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Gunning, R. V. and C. S. Easton. 1994. Endosulfan resistance in *Helicoverpa armigera* (Hubner) in Australia. J. Aust. ent. Soc. 33: 9-12.

Gunning, R. V., C. S. Easton, L. R. Greenup, and V. E. Edge. 1984. Pyrethroid resistance in *Heliothis armiger* (Hubner) (Lepidoptera: Noctuidae) in Australia. J. Econ. Entomol. 77: 1283-1287.

Gunning, R. V., A. L. Devonshire, and G. D. Morres. 1995. Metabolism of esfenvalerate by pyrethroid-susceptible and -resistant Australian *Helicoverpa armigera* (Lepidoptera: Noctuidae). Pestic. Biochem. Physiol. 51: 205-213.

Hamon, N., R. Shaw, and H. Yang. 1996. Worldwide development of fipronil insecticide, pp. 759-765. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Hardee, D. D. And G. A. Herzog. 1997. 50th annual conference report on cotton insect research and control, pp. 809-833. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Harder, H. H., Riley, S. L., S. F. McCann, and D. W. Sherrod. 1997. DPX-MP062: A novel broad-spectrum, environmentally soft, insect control compound, pp. 48-50. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Heller, J. J. and H. Mattioda. 1992. Field evaluation of RH 5992 on lepidopterous pests in Europe. Brighton Crop Protection Conf. - Pests and Diseases.

Hendrix, W. H., III, R. Huckaba, B. Nead, L. Peterson, D. Porteous, and G. Thompson. 1997. Tracer Insect Control-1996 EUP results, pp. 1086-1087. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Huckaba, R. M, L. G. Peterson, and A. W. Weiss. 1996. Result of naturalyte insect control small plot and large experimental use permit trials in the mid-Atlantic and southeast cotton belt during 1995, pp. 874. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Hull, L. A., B. A. Barrett, and E. G. Fajotte. 1991. Foliar persistence and effect of fenoxycarb on *Platynota idaeusalis* (Lepidoptera: Tortricidae) on apple. J. Econ. Entomol. 84: 965-970.

Kaakeh, N., W. Kaakeh, and G. W. Bennett. 1996. Topical toxicity of imidacloprid, fipronil, and seven conventional insecticides to the adult convergent lady beetle (Coleoptera: Coccinellidae). J. Entomol. Sci. 31: 315-322.

Kanga, L. H. B., F. W. Plapp, Jr., M. L. Wall, M. A. Karner, R. L. Huffman, T. W. Fuchs, G. W. Elzen, and J. L. Martinez-Carillo. 1995. Monitoring tolerance to insecticides in boll weevil populations (Coleoptera: Curculionidae) from Texas, Arkansas, Oklahoma, Mississippi, and Mexico. J. Econ. Entomol. 88: 198-204.

Klis, S. F. L., N. J. Nijman, H. P. M. Vijverberg, and J. Van den Bercken. 1991a. Phenylpyrazoles, a new class of pesticide: Effects on neuromuscular transmission and acetycholine responses. Pestic. Sci. 33: 213-222.

Klis, S. F. L., H. P. M. Vijverberg, and J. Van den Bercken. 1991b. Phenylpyrazoles, a new class of pesticides: An electrophysiological investigation into basic effects. Pestic. Biochem. Physiol. 39: 210-218.

Kuhn, D. G., R. W. Addor, R. E. Diehl, J. A. Furch, V. M. Kahmi, K. E. Henegar, D. A. Kremer, G. T. Lowen, B. C. Black, T. P. Miller, and M. F. Treacy. 1993. Insecticidal pyrroles, pp. 219-232. *In* Pest Control with Enhanced Environmental Safety, Am. Chem. Soc. Symp. Ser. 524, 219-232. S. O. Duke, J. J. Menn, and J. R. Plimmer, Jr. (Eds.).

Lovell, J. B., D. P. Wright, Jr., I. E. Gard, T. P. Miller, M. F. Treacy, R. W. Addor, and V. M. Kamhi. 1991. AC 303,630 - an insecticide/acaricide from a novel class of chemistry, pp. 736-737. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Martin, S. H., G. W. Elzen, J. B. Graves, S. Micinski, B. R. Leonard, and E. Burris. 1995. Toxicological responses of tobacco budworms (Lepidoptera: Noctuidae) from Louisiana, Mississippi, and Texas to selected insecticides. J. Econ. Entomol. 88: 505-511.

Menn, J. J. And C. A. Henrick. 1985. Newer chemicals for insect control, pp. 247-365. *In* Agricultural Chemicals of the Future. Rowman and Allanheld, Totowa, NJ.

Miyamoto, J., M. Hirano, Y. Takimoto, and M. Hatakoshi. 1993. Insect growth regulators for pest control with emphasis on juvenile hormone analogs - present status and future prospects. *In* Pest Control with Enhanced Environmental Safety, ACS Symp. Ser. 524. S. O. Duke, J J. Menn, and J. R. Plimmer, Jr. (Eds.).

Mizell, R. F. and M. C. Sconyers. 1992. Toxicity of imidacloprid to selected arthropod predators in the laboratory. Fla. Entomol. 75: 277-280.

Moffat, A. S. 1993. New chemicals seek to outwit insect pests. Science. 261: 550-551.

Mullins, J. W. 1993. A new nitroguanidine insecticide, pp. 183-198. *In* Pest Control with Enhanced Environmental Safety, Am. Chem. Soc. Symp. Ser 524. S. O. Duke, J. J. Menn, and J. R. Plimmer, Jr. (Eds.).

Mullins, J. W. and C. E. Engle. 1993. Imidacloprid (Bay NTN 33893): A novel chemistry for sweetpotato whitefly control in cotton, pp. 719-720. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Murray, D. A. H. And R. J. Lloyd. 1997. The effect of spinosad (Tracer) on arthropod pest and beneficial populations in Australian cotton, pp. 1087-1091. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Ngo, N. D., S. T. Moore, B. W. Minton, W. W. Bachman, and D. V. Allemann. 1995. CGA-215944 for control of *Aphis gossypii* Glover in cotton, pp. 895-899. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Pfluger, W. R. and R. Schmuck. 1991. Ecotoxicological profile of imidacloprid. Pflanzenschutz-Nachrichten Bayer. 44: 145-158.

Pietrantonio, P. V. and J. Benedict. 1997. Effect of new chemistry insecticides towards beneficial insects of cotton, pp. 1339-1340. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Pimprale, S. S., C. L. Besco, P. K. Bryson, and T. M. Brown. 1997. Increased susceptibility of pyrethroid-resistant tobacco budworm (Lepidoptera: Noctuidae) to chlorfenapyr. J. Econ. Entomol. 90: 49-54.

Roush, R. T. and J. C. Daly. 1990. The role of population genetics in resistance research and management, pp. 97-152. *In* Pesticide Resistance in Arthropods. R. T. Roush and B. E. Tabashnik (Eds). Chapman and Hall, New York.

Salgado, V. L., G. B. Watson, and J. J. Sheets. 1997. Studies of the mode of action of spinosad, the active ingredient in Tracer insect control, pp. 1082-1086. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Snodgrass, G. L. 1994. Pyrethroid resistance in a population of tarnished plant bug in the Mississippi delta, pp. 1186-1187. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Snodgrass, G. L. 1996. Glass vial bioassay to estimate insecticide resistance in adult tarnished plant bug (Heteroptera: Miridae). J. Econ. Entomol. 89: 1053-1059.

Thompson, G. D., P. W. Borth, R. M. Huckaba, T. C. Sparks, J. D. Busacca, B. A. Nead, L. G. Peterson, D. J. Porteous, M. C. Shaw, J. R. Richardson, and J. R. Winkle. 1996a. Naturalyte insect control, pp. 758-759. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Thompson, G. D., P. W. Borth, M. C. Shaw, R. W. Huckaba, B. A. Nead, L. G. Peterson, J. M. Richardson, and D. J. Porteous. 1996b. Spinosad and the new naturalyte insect control class, pp. 870-872. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Tomizawa, M. and I. Yamomoto. 1993. Structure-activity relationships of nicotinoids and imidacloprid analogs. J. Pestic. Sci. 18: 91-98.

Treacy, M. F., T. P. Miller, I. E. Gard, J. B. Lovell, and D. P. Wright, Jr. 1991. Characterization of insecticidal properties of AC 303,630 against tobacco budworm, *Heliothis virscens* (Fabricius), larvae, pp. 738-740. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

White, S. M., D. M. Dunbar, R. Brown, B. Cartwright, D. Cox, C. Eckel, R. K. Jansson, P. V. Mookerjee, J. A. Norton, R. F. Peterson, and V. R. Starner. 1997. Emamectin benzoate: A novel avermectin derivative for control of lepidopterous pests in cotton, pp. 1078-1082. *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Whitehead, J. R., P. David, B. Watkins, P. Nester, and R. Lecense. 1993. Performance of Pirate, insecticide mixture, against cotton pests in the mid-south in 1992, pp. . *In* Proceedings Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Wing, K. D., R. A. Slawecki, and G. R. Carlson. 1988. A nonsteroidal ecdysone agonist. Effects on larval lepidoptera. Science. 241: 470-472.

Wu, K., G. Liang, and Y. Guo. 1997. Phoxim resistance in *Helicoverpa armigera* (Lepidoptera: Noctuidae) in China. J. Econ. Entomol. 90: 868-872.

Heliothis/Helicoverpa(H/H)Program Transition-Introduction

The final review of the Five year National Research Plan for the development of suppression technology for H/H was held on October 6, 1997. The preceding report reviews the H/H research conducted since the last meeting. At the close of the review session on October 6, the 1992-1997 the five year plan was completed and a meeting was called for 8:00 a.m. the following day October 7, 1997 to discuss future plans.

At the start of the meeting on October 7, 1997, there was considerable discussion concerning how the planning for these insect pests should proceed. The consensus was that we should develop a new highly focused research and action plan, which will be operated under a virtual laboratory mode. The laboratory will be headed by a virtual Laboratory Director (VLD) who will serve as the program coordinator. Dr. D. D. Hardee was elected to this position.

The VLD was assigned several duties including 1) coordinating the H/H research and action plan, 2) making recommendations related to the management and operation of program activities, 3) promoting timely communication and collaboration for the virtual teams, 4) help to prepare annual progress workshops, reports, and other appropriate periodical reports, and 5) miscellaneous.

The first action of the VLD was to facilitate the development of proposed virtual project titles. The number of projects were limited by resources to no more than seven. Once the project title, project leader and project members were selected, the group were instructed to prepare project summaries. The project summaries were to contain 1) a mission statement, 2) project objectives, 3) approach statement, 4) list of potential cooperators and 5) means of communication (i.e. teleconference, website, etc.). The project summaries were to be completed and forwarded to the VLD by January 1, 1998. Subsequently each team was directed to develop a five-year research/action plan for H/H. The research emphasis areas in the five-year research plan were to be the seven virtual projects for which the project summaries were developed. The project summaries and the corresponding five year plans follow this introduction.

USDA/ARS Virtual Projects on *Heliothis / Helicoverpa*

1. Movement and Migration

Project Leader: John K. Westbrook, College Station, TX

Team Members: Gretchen D. Jones and Juan D. Lopez, College Station, TX; Jeffrey L. Willers, Mississippi State, MS; Sammy D. Pair, Lane, OK; Dennis Nelson, Fargo, ND; Art McIntosh, Columbia, MO; and Rich Hellmich, Ames, IA; Vacancy, Stoneville, MS

Mission Statement: Develop capabilities for predicting the agronomic impact of migrant *Heliothis / Helicoverpa* which can be used to evaluate farm-specific and areawide pest management strategies.

Objectives:

1. Develop technologies and techniques to discriminate the migrant status of individual *Heliothis / Helicoverpa.*

2. Develop applications of new technologies for monitoring adult *Heliothis / Helicoverpa* movement and migration.

3. Develop and validate predictive models of adult *Heliothis / Helicoverpa* movement and migration.

4. Evaluate the impact of migration on population dynamics, resistance management, and agronomic production.

Approach Statement:

Naturally-occurring and artificially-applied markers, genetic identification, and remote sensing will be used to efficiently discriminate between migrant and local *Heliothis / Helicoverpa* cohorts. Methods will be developed to use new detection technologies including the NEXRAD network of operational doppler weather radars for monitoring adult *Heliothis / Helicoverpa* movement and migration. Atmospheric trajectory and dispersal models will be modified and evaluated for prediction of adult *Heliothis / Helicoverpa* movement and migration. Field survey data of insect population dynamics, resistance levels, and agroecosystems will be incorporated in a geographic information system to assess the agronomic impact of migrant *Heliothis / Helicoverpa.*

Cooperators:

Federal

Steve Allen, National Weather Service, League City, TX
Jim D. Ward, National Weather Service, New Braunfels, TX
Nyzette Rydell, National Weather Service, New Braunfels, TX
Paul Yura, National Weather Service, Brownsville, TX

Private Industry

Peter D. Lingren, Trécé Corporation, College Station, TX

University

John C. Schneider, Mississippi State University, Mississippi State, MS
Randy Luttrell, Mississippi State University, Mississippi State, MS
Mike Williams, Mississippi Extension Service, Mississippi State, MS
Blake Layton, Mississippi Extension Service, Mississippi State, MS
Allen Knutson, Texas Agricultural Extension Service, Dallas, TX
Roy Parker, Texas Agricultural Extension Service, Corpus Christi, TX
James H. Matis, Texas A&M University, College Station, TX
David Heckel, Clemson University, Clemson, SC (?)
Gary F. McCracken, University of Tennessee, Knoxville, TN
Ben Balsley, University of Colorado, Boulder, CO
Mike Jensen, University of Colorado, Boulder, CO

Non-Profit Organizations

Merlin D. Tuttle, Bat Conservation International, Austin, TX
Brian Keeley, Bat Conservation International, Austin, TX

Communication:

The project leader will solicit monthly updates from project members by e-mail, and prepare a monthly summary of the updates. The monthly research summary will be sent via e-mail to all project members, and posted on a World Wide Web homepage. Project members will submit annual summaries of research progress and technology transfer to the project leader by Dec. 1; the progress reports will be incorporated into an annual report that will be submitted to the *Heliothis / Helicoverpa* Program Coordinator by Jan. 1. Requests for technical or cooperative assistance will be communicated to the project leader on an as-needed basis for development of formal requests to the *Heliothis / Helicoverpa* Program Coordinator, NPS, and other project leaders. The project team will hold a meeting or teleconference annually to discuss research progress, needs, and plan collaborative research.

Heliothis / Helicoverpa Five Year Research/Action Plan (1998)

Area 1. Movement and Migration

Research Approaches:	Year 1	Year 2	Year 3	Year 4	Year 5
1) Develop technologies and techniques to discriminate the migrant status of individual Heliothis / Helicoverpa (H/H)	Determine alternative spring foraging resources for H/H in the Brazos Valley Develop system to detect dispersing adult H/H using videographic detection and image analysis Conduct lab studies of artificial markers for adult H/H Evaluate inherent genetic markers for adult H/H	Determine alternative spring foraging resources for H/H in the Brazos Valley Conduct field studies of H/H dispersal using videography and image analysis Conduct field studies of adult H/H dispersal using artificial markers Evaluate inherent genetic markers for adult H/H	Determine physiological differences between migrants and non-migrants Continue field studies of H/H dispersal using videography and image analysis Develop new methods of aerial capture of adult H/H Conduct lab studies using trace element markers of H/H	Determine physiological differences between migrants and non-migrants Conduct field studies of H/H dispersal using trace element markers	Determine physiological differences between migrants and non-migrants Continue field studies of H/H dispersal using trace element markers
2) Develop applications of new technologies for monitoring adult H/H movement and migration	Conduct field studies to measure (NEXRAD) radar reflectivity and doppler velocity associated with H/H migrations	Continue field studies to measure (NEXRAD) radar reflectivity and doppler velocity associated with H/H migrations Identify plants which can be used as attractants for H/H	Derive algorithms to estimate the concentration and displacement of populations of migrating H/H by (NEXRAD) radars Develop monitoring systems based on plants or plant compounds attractive to H/H	Conduct small-scale field study using harmonic radio diodes as tags of dispersing adult H/H	Conduct large-scale field study using harmonic radio diodes as tags of dispersing adult H/H
3) Develop and validate predictive models of adult H/H movement and migration	Develop empirical parameterizations of H/H flight behavior	Modify H/H flight trajectory and dispersal models using empirical parameterizations	Conduct sensitivity analysis of insect flight trajectory and dispersal models	Validate insect flight trajectory and dispersal models	Technology transfer of trajectory and dispersal models
4) Evaluate the impact of migration on population dynamics, resistance management, and agronomic production	Map H/H populations and habitats in the Brazos Valley using GPS, remote sensing, and GIS Determine the amount of herbaceous "wild" foraging hosts in the Brazos Valley	Continue to map H/H populations and habitats in the Brazos Valley using GPS, remote sensing, and GIS Determine the amount of woody "wild" foraging hosts in the Brazos Valley	Estimate local population dynamics of H/H in the Brazos Valley using meteorological and host plant data	Simulate the impact of migration on population dynamics, resistance management, and agronomic production	Validate simulations of the impact of migration on population dynamics, resistance management, and agronomic production

USDA/ARS Virtual Projects on *Heliothis / Helicoverpa*

2. Biorational Control Strategies

Project Leader: Juan D. Lopez, Jr., College Station, TX

Team Members: K. Beerwinkle, R. Nachman, T. Shaver, J. Westbrook, College Station, TX; E. Mitchell, S. Mayer, R. Meagher, P. Teal, Gainesville, FL; J. Klun, A. Raina, Beltsville, MD; S. Pair, Lane, OK; T. Coudron, A. McIntosh, Columbia, MO; Vacancy, Stoneville, MS

Mission Statement: Develop biorational control strategies for the management of *Heliothis / Helicoverpa* using biotoxins, phytoattractants, repellents, and mating disruptants.

Objectives:

1. Discover and develop peptides, peptidomimetic agonists/antagonists, and wasp toxins as potential disruptors of behavior and physiology.

2. Determine the mode of action of biotoxins.

3. Develop and evaluate delivery systems for phytoattractants, toxicants, and biotoxins in host plants, microbial vectors, and incorporation into baits.

4. Improve classic and develop new approaches for mating disruption.

Approach Statement:

Natural peptide hormones and synthetic peptide/pseudopeptide libraries will be evaluated for biological activity. Peptidominetics of known peptides which influence or regulate critical physiological or behavioral functions with resistance to peptidase or environmental degradation and enhanced oral or topical delivery characteristics will be developed. Biotoxins will be characterized and will be expressed in plants and microbial vectors. Phytoattractants for use in attracticidal bait formulations will be identified. Application technology (ground and aerial) will be evaluated or developed. Pheromone component(s) will be evaluated and pheromone analogs will be designed for enhanced mating disruption capabilities. Studies of the diffusion of volatiles will be conducted.

Cooperators:

Private Industry

BASF Corporation, Raleigh, NC
Dupont, Wilmington, DE

University

Roger W. Meola, Texas A&M University, College Station, TX

Communication:

Research progress updates from project team members will be submitted quarterly via e-mail to the project leader with a copy to all team members. An annual summary of research progress will be submitted to the project leader by December 1 of each year for development of an annual report to be submitted by January 1 to the *Heliothis / Helicoverpa* Project Coordinator. Requests for technical or cooperative assistance will be communicated to the project leader on an as-needed basis for development of formal requests to the *H / H* Program Coordinator, NPS, and other project leaders. The project team will meet preferably annually but at a minimum biennially to discuss research progress, needs, and plan coordinated research.

Heliothis / Helicoverpa Five Year Research/Action Plan (1998)
Area 2. Biorational Control Strategies

Research Approaches:	Year 1	Year 2	Year 3	Year 4	Year 5
1) Discover and develop peptides, peptidomimetic agonists/antagonist, wasp toxins, and other chemicals from different sources as potential disruptors of behavior and physiology.	Screen peptides and old and new chemistries for biological activity. Synthesize peptidase - resistant insect regulatory peptide mimics in sufficient quantities for biological assays. Complete ecdysis-arresting protein (EAP) gene isolation. Isolate venom from *Necremnus.* Prepare insect - pseudopeptide - mimic libraries and evaluate in *in vitro* H/H bioassays.	Contine screenings for biological activity. Amplify cDNA library from EAP. Purify arrestant from *Necremnus* venom. Test insect peptide mimics in *in vitro* H/H bioassay systems.	Continue screenings for biological activity. Conduct physiological analysis of *Necremnus* arrestant. Test insect peptide or psuedopeptide mimics in *in vitro* H/H assays via injection and develop topically/orally active mimic versions.	Continue screenings for biological activity. Sequence *Necremnus* arrestant. Test topically/orally-active pest management agent versions in *in vitro* H/H bioassay systems.	Continue screenings for biological activity. Isolate gene for *Necremnus* arrestant.
2) Determine mode of action of biotoxins.	Determine tissue responses of EAP and *Necremnus* venom.	Conduct histochemical analysis of EAP, *Necremnus* arrestant and other biologically-active materials in Lepidopteran insects.	Continue mode of action (MOA) determinations. Identify receptor site for EAP. Test receptor site of EAP for binding of *Necremnus* arrestant.	Determine receptor binding of epitope of EAP and receptor binding of *Necremnus* arrestant. Continue MOA determination.	Isolate receptor site for EAP and *Necremnus* arrestant. Continue MOA determination.

3) Develop and evaluate delivery systems for phytoattractants, toxicants, and biotoxins in host plant and microbial vectors or incorporation into baits and conventional application technology.	Identify volatile components and feeding substrates from various sources such as adult host plants. Determine adult H/H and non-target species response to traps baited with individual components or blends of components to identify phytoattractants.	Continue bioassays in traps and in the field to optimize lure formulations and feeding substrates.	Continue bioassays to refine lure and feeding substrate combinations. Determine compatability of toxicants and biotoxins with lure/feeding substrate combinations. Develop practical conventional delivery systems. Determine optimum bait/field position and effect on target/non target insects. Construct/screen plasmid vector for EAP.	Evaluate delivery system in large scale tests. Engineer plant or virus vector for EAP. Continue refinement of delivery system for newly discovered biotoxins.	Continue large plot tests and evaluate potential as a management tool. Analyze EAP-engineered products for activity. Transfer technology.
4) Improve classic and develop new approaches for mating disruption.					

USDA/ARS Virtual Projects on *Heliothis / Helicoverpa*

3. Ecologically-Based Management

Project Leader: P. Glynn Tillman, Tifton, GA

Team Members: W. J. Lewis, Tifton, GA; J. H. Tumlinson, Gainesville, FL

Mission Statement: To develop and foster the adoption of a sustainable management system for cotton, peanuts, and other crops in the southeast that remediates the incidence and cost of *Heliothis / Helicoverpa* as pests and promotes conservation of soil, water, and other natural resources.

Objectives:

1. A year round habitat management program that promotes the abundance and effectiveness of natural enemies and natural enemy/pest balances through uses of cover crops, conservation tillage, companion cropping, appropriate crop rotations, etc.

2. The use of crop varieties and agronomic management practices that optimize the genotypic capacity and phenotypic expression of inherent attributes of crops, including plant signaling/attraction of natural enemies, antifeedants, extrafloral nectaries, etc. These practices will involve understanding and selective breeding/engineering of varieties with desired traits as well as agronomic practices such as fertility and water management that optimize the expression of these traits.

3. Optimal/compatible use of therapeutics for other pests, such as use of pesticides for weeds, diseases, and other insects. The avoidance of direct and indirect disruption of beneficial organisms with other inputs will be emphasized.

Approach Statement:

Develop a total management system that remediates the occurrence of *Heliothis / Helicoverpa* as pests by maximizing ecosystem strengths and crop defenses and minimizing undesired disruptions through agronomic interventions. An integrated farm approach involving environmentally sound and sustainable practices such as conservation tillage, appropriate rotations, judicious inputs of fertilizers, pesticides, and petroleum energies will be emphasized.

Cooperators:

University

John Ruberson, University of Georgia
Jim Hook, University of Georgia
Glen Harris, University of Georgia
Rick Reed, University of Georgia
Dean Page, NRCS

Private

Alton Walker, Grower
Max Carter, Grower
Lamar Black, Grower
Tommy Harrison, Grower
Wayne Fussell, Grower

Communication:

E-mail/Cotton Patch reports, Quarterly and semiannual meetings, monthly conference calls.

Heliothis / Helicoverpa Five Year Research/Action Plan (1998)
Area 3. Ecological Management

Research Approaches:	Year 1	Year 2	Year 3	Year 4	Year 5
1) Determine attributes and benefits of various plants (crops and refugia) for enhancing the presence and effectiveness of natural enemies.	Create a guide providing information on the attributes of candidate plants for enhancing the performance of natural enemies.	Assess the presence and effect of various attributes of selected plants in greenhouse and small plot field experiments.	Continue second year assessments, and evaluate combinations of candidate plants.	Expand evaluations to full-scale field trials.	Begin incorporating selected plants into production systems.
2) Identify plant/herbivore foraging cues to maximize crop defenses.	Confirm behavioral significance of host kairomones used by parasitoids.	Evaluate electro-physiological activity of unpurified host extracts.	Purify host extracts (contingent upon access to analytical equipment or previously collected data).	Evaluate behavioral significance and electro-physiological activity of purified extracts.	Chemically characterize active kairomones with gas chromatography and mass spectrometry (contingent upon access to analytical equipment or previously collected data), and identify ways in which these materials may be used to supplement existing lepidopteran pest management technology.
3) Determine agronomic practices that maximize expression of plant attributes which enhance desirable natural enemy/pest balances.	Conduct greenhouse and small field plot studies to identify key factors (e.g., soil quality, water stress, and systemic pesticides) that affect the expression of desired plant attributes.	Conduct field studies to assess the effect of various combinations of the factors identified in previous year.	Conduct field trials to assess how current farming practices (e.g., fertilization, irrigation and pesticide use) affect the expression of desired plant attributes.	Evaluate modified farming practices that enhance the expression of desired plant attributes.	Begin demonstrations of modified farming practices that enhance expression of desired plant attributes as a component of competitive and sustainable farming practices.

USDA/ARS Virtual Projects on *Heliothis / Helicoverpa*

4. Pathogens

Project Leader: Douglas A. Streett, Stoneville, MS

Team Members: Douglas Streett and Joe Mulrooney, Stoneville, MS; John Hamm and Harold Sumner, Tifton, GA; Art McIntosh, Carlo Ignoffo, and Jim Grasela, Columbia, MO

Mission Statement: Develop and implement technologies utilizing entomopathogens for the control of *Heliothis / Helicoverpa* in order to reduce the reliance on chemical insecticides.

Objectives:

1. Isolate, identify, and characterize entomopathogens for the control of *Heliothis / Helicoverpa*.

2. Evaluate field efficacy of naturally-occurring and recombinant entomopathogens for the control of *Heliothis / Helicoverpa*.

3. Assess the fate and expression of naturally-occurring and recombinant entomopathogens for the control of *Heliothis / Helicoverpa*.

4. Develop and improve mass production systems for entomopathogens used to control *Heliothis / Helicoverpa*.

5. Evaluate potential development of resistance to toxins produced by genetically-altered baculoviruses to control *Heliothis / Helicoverpa*.

Approach Statement:

Entomophathogens, which include protozoa, viruses, bacteria, fungi, and nematodes are used as microbial control agents of *Heliothis* and *Helicoverpa*. The successful development of these agents will depend on addressing a number of issues, including characterization, efficacy, fate, mass production, and potential for resistance development. Indigenous and nonindigenous entomopathogens associated with *Heliothis* and *Helicoverpa* will be isolated and characterized. Field trials will be conducted to determine the efficacy of naturally-occurring and recombinant entomopathogens, and to develop formulations and improve application technology. Epizootiological data will be collected for indigenous, nonindigenous, and genetically-altered entomopathogens to assess the impact of biotic and abiotic factors on environmental fate and expression. Methods will be developed to improve the large scale *in vivo* or *in vitro* production of entomopathogens. Host-toxin interactions will be investigated to determine the potential for

resistance in *Heliothis / Helicoverpa*.

Cooperators:

Federal

Michael McGuire, Peoria, IL
Martin Shapiro, Beltsville, MD
James Vaughn, Beltsville, MD

International

Peter Christian, CSIRO, Canberra, Australia

Communication:

A team meeting will be held each year either at the ESA National meeting or the S-265 meeting to review progress and discuss future efforts. Project members will submit a brief annual summary of research progress and technology transfer to the project leader by December 15; that will be submitted to the *Heliothis / Helicoverpa* program coordinator by January 1. E-mail messages will also be used to communicate with members of the team to coordinate cooperative research efforts.

Heliothis / Helicoverpa Five Year Research/Action Plan (1998)
Area 4. Pathogens

Research Approaches:	Year 1	Year 2	Year 3	Year 4	Year 5
1) Isolate, identify, and characterize pathogens.	Survey for pathogens of H/H in west-central Mexico. Bioassay pathogens from Mexico against H/H. Collect indigenous and non-indigenous pathogens. Select for UV stable strains of HzSNPV, establish *in vivo* and *in vitro* protocols using NOV.	Continue survey for pathogens of H/H in west-central Mexico. Initiate *in vivo* and *in vitro* studies. Identify potential pathogenic agents.	Recombine UV-stable NOV and P^+ into OB. Bioassay, determine host range.	Evaluate modified UV-NOV + OB in lab and greenhouse. Conduct field trials.	Conduct large scale field trials.
2) Evaluate field efficacy of pathogens.	Assess impact of host-plant on efficacy and persistence of HzSNPV.	Field test formulations of AfMNPV against *H. zea*. Continue to assess impact of host-plant on efficacy and persistence of HzSNPV.	Evaluate formulations of AcMNPV and HzSNPV on cotton for persistence in small plots.	Continue to evaluate formulations of AcMNPV and HzSNPV on cotton for persistence in small plots.	Conduct large scale field evaluations on cotton and determine optimum application technology.
3) Assess fate and expression of pathogens.	Conduct lab tests of formulations of AfMNPV against *H. zea*. Determine spp. of *Steinernema* and *Heterorhabditis* in soil at Tifton, GA and apply *S. riobravis*. Generate and/or secure strains and establish standard protocols to evaluate wild type and baculovirus recombinants. Assess efficacy of recombinant HzSNPV in field cages; effects on non-targets.	Determine persistence of *S. riobravis* in the soil at Tifton, GA. Study expression of recombinant genes *in vivo* and *in vitro*. Continue to assess efficacy of recombinant HzSNPV in field cages; effects on non-targets.	Select and lab test most promising recombinants or strains. Assess efficacy and persistence of recombinant HzSNPV in small plots; effects on non-targets.	Arrange for field tests of promising candidates. Assess efficacy and persistence of recombinant HzSNPV in small plots; effects on non-targets.	Large scale field tests. Assess efficacy of recombinant HzSNPV in large plots.

4) Develop and improve mass production of pathogens.	Initiate *in vitro* studies for mass production of baculoviruses. Lab evaluation of *in vivo* production of recombinant AcMNPV and HzSNPV.	Optimize *in vitro* conditions for mass production. Continue lab evaluation of *in vivo* production of recombinant AcMNPV and HzSNPV.	Evaluate potential additives to enhance production. Expand production system to mass production level; assess recombinant AcMNPV and HzSNPV.	Assess potential for large scale production. Continue evaluation of mass production system to assess recombinant AcMNPV and HzSNPV.	Arrange for *in vitro* commercial large scale production. Begin technology transfer to commercial interest
5) Evaluate potential for resistance to pathogens.	Initiate lab studies and develop bioassays.	Continue lab studies.	Continue lab studies and finalize parameters if resistance develops.	Develop resistance management plan and conduct field studies.	Continue to develop field plans to monitor resistance

USDA/ARS Virtual Projects on *Heliothis / Helicoverpa*

5. Beneficial Insects

Project Leader: James E. Carpenter, Tifton, GA

Team Members: Pat Greany and Everett Mitchell, Gainesville, FL; Harold Sumner and Glynn Tillman, Tifton, GA; Don Nordlund, Mississippi State, MS; Livy Williams, Stoneville, MS; Guillermo Logarzo, Buenos Aires, Argentina; Vacancy, France

Mission Statement:

Enhance the role of beneficial insects in suppressing populations of *Heliothis / Helicoverpa* through introduction of new, exotic species, augmentative releases of established species, and by integration of beneficial insects with other biorational control approaches.

Objectives:

1. Identify new candidate natural enemies for introduction and evaluation.
2. Develop improved mass rearing capabilities for natural enemies and their host/prey.
3. Develop better means for evaluating impact of *Heliothis / Helicoverpa* natural enemies in natural habitats and in crops.
4. Develop ancillary strategies to enhance natural populations of beneficials, such as providing F1 steriles as hosts, supplemental food, localized nursery crops (trap crops), and refugia.
5. Develop improved spatial and temporal targeting and distribution technologies for lab-reared insects (both natural enemies and host/prey).
6. Determine/improve/select for tolerance of natural enemies to insecticides.

Approach Statement:

Foreign locations will be surveyed for the presence of new candidate natural enemies of *Heliothis / Helicoverpa*. Identified natural enemies with the most potential will be introduced and evaluated. Automated systems for all rearing processes of *Heliothis / Helicoverpa* and selected natural enemies will be developed and improved. Artificial diets and diet packaging systems will be developed and evaluated for their performance and shelf life. Factors influencing the

population dynamics, dispersal, and impact of natural enemies of *Heliothis / Helicoverpa* will be determined The role of natural habitats and crop plants on the biology, phenology, and demography of *Heliothis / Helicoverpa* and natural enemies will be defined. Natural and augmented populations of beneficial insects will be enhanced by providing the environment with sterile hosts and supplemental food, and by establishing localized nursery crops, trap crops and refugia. Automated technologies for distributing both natural enemies and host/prey in the field will be developed and evaluated.

Cooperators:

Federal

Dale Gelman, USDA-ARS, Beltsville, MD
Tom Coudron, USDA-ARS, Columbia, MO
Rick Edwards, USDA-ARS, Albany, CA
Steve Ferkovich, USDA-ARS, Gainesville, FL
John Hamm, USDA-ARS, Tifton, GA
Joe Lewis, USDA-ARS, Tifton, GA
Wayne Reeves, USDA-ARS, Auburn, AL

Private Industry

Glen Hammes, DuPont, Hawkinsville, GA
John Altom, Valent, Perry, GA
Lance Petersen, Dow Agrosciences, Tallahassee, FL
Paschol Pearce, Farmer, Appling County

University

John Ruberson, University of Georgia, Tifton, GA
Gary Herzog, University of Georgia, Tifton, GA
Philip Roberts, University of Georgia, Tifton, GA
Glen Harris, University of Georgia, Tifton, GA
Jim Hook, University of Georgia, Tifton, GA
Michael Jay Moore, University of Georgia, Tifton, GA

Communication:

The project leader will solicit quarterly updates from project members via e-mail, and prepare a monthly summary of the updates. The monthly research summary will be sent via e-mail to all project members, and posted on a World Wide Web homepage. Project members will submit annual summaries of research progress and technology transfer to project leader by Dec. 1; the progress reports will be incorporated into an annual report that will be submitted to the *Heliothis/ Helicoverpa* Program Coordinator by Jan. 1. Requests for technical or cooperative assistance will be communicated to the project leader on an as-needed basis for development of formal requests

to the *Heliothis/ Helicoverpa* Program Coordinator, NPS, and other project leaders. The project team will hold a meeting or teleconference annually to discuss research progress and needs and to plan collaborative research.

Heliothis / Helicoverpa Five Year Research/Action Plan (1998)
Area 5. Beneficial Insects

Research Approaches:	Year 1	Year 2	Year 3	Year 4	Year 5
1) Develop packaging systems for artificial diets (e.g., diet capsules, gelled media in thermoformed cells, diet packets) for selected candidate beneficial insects.	Evaluate/create films/ encapsulants/coatings for use in diet packaging and encapsulation systems; test biodegradable material for packaging.	Develop mechanized systems to utilize films/coatings with diet.	Scale up production systems capacity.	Pilot test production systems.	Integrate diet and packaging methods into automated mass rearing system
2) Evaluate addition of kairomones or other phagostimulants to improve acceptance of artificial diets by beneficial insects.	Perform bioassays to determine whether semiochemicals are influential in feeding.	Acquire behaviorally-active extracts; initiate fractionation.	Perform chemical analyses to identify active compound(s).	Incorporate active compound(s) into diets.	Complete studies; integrate with diets and diet packages.
3) Develop food supplements for infield use for predators.	Evaluate/develop biodegradable packaging material for predator diets.	Evaluate predator acceptance; add kairomones if needed.	Develop dispensing system(s)	Evaluate benefits in the field.	Complete in-field studies
4) Develop improved mass rearing capabilities for beneficial insects and their host/prey.	Develop an improved lepidopterous egg collection system, an automated system for packaging artificial diet for mass rearing *Chrysoperla* spp. and continue advances in development of an artificial diet for *Trichogramma* spp.	Automate the process for harvesting *Chrysoperla* spp. eggs, develop an improved system for harvesting H/H pupae from rearing trays, and begin automation of an *in vitro* rearing system for *Trichogramma* spp.	Continue the development of automated mass rearing systems for *Chrysoperla* spp. and *Trichogramma* spp. and improvements to the rearing system for H/H	Continue studies of Year 3 and begin development of rearing systems for identified high priority beneficial insects.	Continue studies of Year 4
5) Improve methods of making diet, mixing, cooking, etc. Apply these principles to scaling up for mass production of beneficial insects.	Find cheapest ingredients and test them for increasing scale of production.	Incorporate industrial scale technology and equipment for producing diet.	Conduct bioassays and economic assessment of up scaled methods.	Continuation of 1, 2, 3.	Continuation of 4

6) Determine limiting factors for reproduction and fecundity in artificially reared beneficial insects.	Establish physiological baselines for reproduction (mating, fecundity, hormonal controls, etc.) in artificially reared insects. Implement the use of insect-derived diets (to include insect cell culture technology) to assist in studies with entomophagous insects.	Continue Year 1 studies. Refine our understanding of the bridge between nutrition and reproduction.	Continue Year 1&2 studies; integrate information on reproduction and fecundity into routine rearing protocols.	Continue Year 1, 2, & 3 studies; publish results.	Continue Year 1-4 studies, publish results
7) Evaluation of new exotic species as beneficial insects against H/H.	Survey foreign locations for new candidate beneficial insects. Continue monitoring introduced beneficial insects for establishment and impact.	Continue Year 1 activities Introduce new beneficial insect candidates.	Continue Year 1&2 studies, publish results.	Continue Year 1,2, & 3 studies, publish results.	Continue Year 1-4 studies, publish results
8) Study density-dependent relationships.	Study effects of superparasitism on adult *Archytas marmoratus* eclosion and other parasitoids.	Determine effect of parasitism rate on superparasitism of *Archytas marmoratus* and other parasitoids in the field.	Continue studying superparasitism, and determine functional response of *Archytas marmoratus* and other parasitoids to changes in host density.	Continue studying functional response of *Archytas marmoratus* and other parasitoids to changes in host density.	Finalize research activity and publish results.
9) Develop applied strategies for beneficial insects.	Study methods to infest early season trap crops with sterile progeny of irradiated pests.	Continue Year 1 activities and begin to evaluate suitability of the artificially infested, sterile larvae as hosts for beneficial insects.	Continue Year 2 activities.	Conduct small field trials to determine the ability of beneficial insects reared on artificially infested, sterile larvae to influence pest populations.	Conduct large field demonstrations of concepts as warranted.
10) Determine attributes and benefits of various plants (crop & refugia) for enhancing the presence and effectiveness of beneficial insects.	Create a guide providing information on the attributes of candidate plants for enhancing performance of beneficial insects.	Assess the presence and effect of various attributes of selected plants in greenhouse and small plot field experiment.	Continue second year assessments, and evaluate combinations of candidate plants.	Expand evaluation to full-scale field trials.	Begin incorporating selected plants into production systems
11) Study the presence, movement, and effectiveness of beneficial insects in agroecosystems.	Develop an array of monitoring methods to detect natural enemy presence (ground and plant dwelling) in agroecosystems.	Evaluate movements of beneficial insects among natural habitats and cropping systems.	Develop methods to assess the effectiveness of beneficial insects for controlling pests in agroecosystems.	Integrate methods for monitoring the presence, movement and effectiveness of beneficial insects in agroecosystems.	Incorporate developed monitoring tools into sustainable pest management programs.

12) Determine the factors influencing dispersal, and subsequent impact, of beneficial insects in the Mississippi Delta.	Characterize natural enemy dispersal from spring weeds to crops.	Continue Year 1 studies and determine the relationships between spring weed and crop phenologies and natural enemy dispersal.	Study the dispersal of beneficial insects in cultivated crops.	Continue Year 3 studies and determine the influence of preferred spring weeds on natural enemy dispersal to crops.	Summarize results and propose further studies
13) Define the biology, phenology and demography of beneficial insects and H/H on spring host plants.	Determine the degree to which early-season populations of hosts and beneficial insects are synchronized.	Continue Year 1 studies and determine developmental, reproductive, and mortality rates of H/H on spring weed hosts.	Continue demographic studies and identify spring weeds that enhance the life history traits of beneficial insects (e.g., by improving nutrition).	Continue Year 3 studies and see year 4 above.	Summarize results and propose further studies
14) Evaluate application of beneficial insects and their host/prey.	Apply beneficial insects with non-automated methods to establish parameters that influence success in the field.	Design and construct equipment and components for application of beneficial insects and their host/prey.	Modify application equipment as needed. Begin design and construction of application equipment for other beneficial insects.	Field test and modify application equipment. Determine efficiency of application and conduct field evaluations of pest control.	Establish standard procedures and provide recommendations

USDA/ARS Virtual Projects on *Heliothis / Helicoverpa*

6. Transgenic Crop Interactions and Host Plant Resistance

Project Leader: Robert E. Lynch, Tifton, GA

Team Members: Johnie Jenkins, Jack McCarty, Mississippi State, MS; Doug Sumerford, Dick Hardee, Vacancy, Stoneville, MS; Bill Wiseman, Neil Widstrom, Baozhu Guo, Robert Lynch, Tifton, GA; Bruce Hibbard, Mike McMullen, Columbia, MO; Dick Wilson, Rick Hellmich, Ames, IA; Sam Pair, Lane, OK

Mission Statement: Develop resistant germplasm using classical or transgenic methods, monitor resistance to transgenic genes, and evaluate the impact of resistant germplasm in areawide pest management strategies for *Heliothis / Helicoverpa*.

Objectives:

1. Develop corn, cotton, and peanut germplasm with resistance to *Heliothis / Helicoverpa* using conventional selection and breeding procedures.

2. Evaluate transgenic germplasm for efficacy in the management of *Heliothis / Helicoverpa* and develop IPM programs to effectively utilize the germplasm.

3. Evaluate the impact of *Heliothis / Helicoverpa* resistant germplasm on the population dynamics of these insects for potential implementation in an areawide management program.

4. Work with other agencies to assist in the development of resistance management programs and/or monitor development of resistance to *B.t.* genes in transgenic crops.

Approach Statement:

Plant resistance to insects is one of the most versatile, effective, and economical means of managing economic insect pest populations. Germplasm has been or is being identified and developed with resistance to *Heliothis / Helicoverpa*. Transgenic cotton, corn, and peanut also offer great potential for the management of *Heliothis / Helicoverpa* populations. Proper utilization of this germplasm in a sustainable system requires preliminary research to define the effects of the resistant germplasm on *Heliothis / Helicoverpa* populations, interactions with entomophagous insects, and potential for the development of resistance.

Cooperators:

Private Industry

David Isenhour, Dekalb Genetics, Inc., Dekalb, IL
Paula Davis, Monsanto Company, St. Louis, MO
Doug Plaisted, Novartis Seeds, Inc., Nampa, ID
Debra Warnick, Novartis Seeds, Inc., Gilroy, GA
Wesley Houghton, Novartis Seeds, Inc., Naples, FL
Jon Sagers, Novartis, Inc., Stanton, NM
Monsanto Agricultural Co.
Delta and Pine Land Co.
Suregrow Seed Co.
Paymaster Technologies
Stoneville Pedigreed Seed Co.
Mycogen Company
Agrevo/Cotton Seed Int.

University

Randy Luttrell, Mississippi State University, Mississippi State, MS
John van Duyn, North Carolina State University, Raleigh, NC
Galen Dively, University of Maryland, College Park, MD
Bill Hutchison, University of Minnesota, St. Paul, MN
Julie Stavisky, University of Florida, Quincy, FL

Communication:

The project leader will initiate communication between all Team Members by preparing a list of mailing addresses, e-mail addresses, and FAX numbers and distributing the list to all members. A brief, quarterly update will be solicited from Team Members, consolidated into a report, and shared with all Team Members, the Virtual Project Laboratory Director, and NPL Bob Faust. All Team Members will submit annual summaries of their research to the project leader for preparation of an annual progress report. This annual progress report will then be distributed to each Team Member, the *Heliothis / Helicoverpa* Virtual Laboratory Director, and NPL. Team Members will hold a planning/coordination meeting at the *Heliothis / Helicoverpa* Research and Planning Meeting or by teleconference annually to discuss program needs, research progress, and plan collaborative research.

Heliothis / Helicoverpa Five Year Research/Action Plan (1998)
Area 6. Transgenic Crop Interactions & HPR

Research Approaches:	Year 1	Year 2	Year 3	Year 4	Year 5
Conventional Corn: 1) Isolate, identify, and characterize resistance.	Conduct field and laboratory research to identify resistance to *H. zea*.	Conduct field and laboratory research to identify resistance to *H. zea*.	Conduct field and laboratory research to identify resistance to *H. zea*.	Initiate transfer of resistance to elite germplasm.	Continue transfer of resistance to elite germplasm.
2) Evaluate field efficacy of resistant germplasm.	Evaluate efficacy of resistant germplasm under field conditions.	Evaluate efficacy of resistant germplasm under field conditions.	Design replicated tests in cooperation with other disciplines.	Assist in design and tests of resistance with cooperators.	Assist in design and tests of resistance with cooperators
3) Conduct chemical analyses to determine mechanism of resistance.	Conduct maysin analyses on resistant accessions or other analyses on non-maysin accessions. Conduct field/lab bioassays.	Conduct maysin analyses on resistant accessions or other analyses on non-maysin accessions. Bioassay.	Conduct maysin analyses on resistant accessions or other analyses on non-maysin accessions. Bioassay.	Conduct maysin analyses on resistant accessions or other analyses on non-maysin accessions. Bioassay.	Conduct maysin analyses on resistant accessions or other analyses on non-maysin accessions. Bioassay.
4) Characterize the genetic basis of flavone silks in corn.	Study populations designed to define the role of chalcone synthase, salmon silks, and the a1 genes.	Continue population studies and focus on gene expression studies to define the role of genes.			Validate simulations of the impact of migration on population dynamics, resistance management, and agronomic production
5) Characterize the genetic basis of chlorogenic acid synthesis in corn silks.	Study populations designed to define genes involved in the 9C pathways.	Continue population studies and focus on gene expression studies to define the role of genes.			
6) Conduct bioassay to define the role of chemicals in resistance in corn.	Conduct bioassays to define the role of 3-deoxyanthocyanins in resistance	Conduct bioassays to define the role of chlorogenic acid in resistance.			
7) Evaluate resistant germplasm within an IPM system.	----	----	Conduct field evaluations to demonstrate effectiveness of resistant germplasm.	Continue evaluation of resistant material in an IPM systems approach.	Continue evaluation of resistant material in an IPM systems approach.
8) Release resistant germplasm to industry.	----	----	----	Publish description of resistant germplasm in Crop Science. Multiply seed.	Provide seed as requested to both public and private breeders.

9) Work with industry to transfer corn earworm resistance due to maysin to sweet corn.	Continue maysin analyses of backcross generations to identify those with high maysin.	Prepare test crosses for evaluation under field conditions. Continue backcrosses. Make high maysin x *B.t.* crosses.	Continue evaluation of test crosses and backcrosses. Conduct preliminary evaluations of high maysin x *B.t.* crosses.	Continue evaluation of high maysin x *B.t.* crosses.	
***B.t.* Corn:** 1) Evaluate *B.t.* field and sweet corn for resistance to insects.	Evaluate corn germplasm in the field for resistance to *H. zea* and *S. frugiperda*.	Continue field evaluation for resistance to *H. zea* and *S. frugiperda*.	Determine tissue in which the toxin is expressed via bioassays against insects in the lab.	Work with industry to get EPA approval for use of resistant lines.	Continue to assist in EPA approval process for *B.t* corn.
2) Develop IPM programs using *B.t.* sweet corn.	Determine the number and timing of insecticide applications to prevent insect damage to ears.	Continue studies on insecticide applications using *B.t.* sweet corn.	Conduct planting date x insecticide studies to determine optimum IPM approaches using *B.t.* sweet corn.	Continue planting date x insecticide studies.	Publish IPM approach to managing insects using *B.t* sweet corn
Conventional Cotton: 1) Genetic selection and breeding.	Screen available germplasm and primitive stocks for natural resistance genes. Develop breeding lines with resistance genes when identified.	Screen available germplasm and primitive stocks for natural resistance genes. Develop breeding lines with resistance genes when identified.	Screen available germplasm and primitive stocks for natural resistance genes. Develop breeding lines with resistance genes when identified.	Screen available germplasm and primitive stocks for natural resistance genes. Develop breeding lines with resistance genes when identified.	Screen available germplasm and primitive stocks for natural resistance genes. Develop breeding lines with resistance genes when identified.
***B.t.* Cotton:** Transgenic germplasm efficacy.	Work with industry to evaluate new transgenes for resistance and to determine efficacy of cultivars bred to express transgenes.	Work with industry to evaluate new transgenes for resistance and to determine efficacy of cultivars bred to express transgenes.	Work with industry to evaluate new transgenes for resistance and to determine efficacy of cultivars bred to express transgenes.	Work with industry to evaluate new transgenes for resistance and to determine efficacy of cultivars bred to express transgenes.	Work with industry to evaluate new transgenes for resistance and to determine efficacy of cultivars bred to express transgenes.
***B.t.* Peanut:** 1) Determine efficacy of different peanut isolates.	Conduct laboratory bioassays to identify lines with high levels of resistance to *H. zea*.	Conduct laboratory bioassays to identify lines with high levels of resistance to *H. zea*.	Continue evaluations for resistance to *H. zea*.	Continue evaluations for resistance to *H. zea*.	Continue evaluations for resistance to *H. zea*.

2) Evaluate wild *Arachis* species for resistance.	Conduct laboratory bioassays to identify resistance to *H. zea*.	Conduct laboratory bioassays to identify resistance to *H. zea*.	Initiate studies to characterize resistance to *H. zea*.	Continue studies to characterize resistance to *H. zea*.	Work with peanut breeders to transfer resistance to elite peanut lines.

USDA/ARS Virtual Projects on *Heliothis / Helicoverpa*

7. Efficient Use and Preservation of Insecticides

Project Leader: Buddy Kirk, College Station, TX

Team Members: Buddy Kirk, Clint Hoffmann, Juan Lopez, College Station, TX; Dick Hardee, Joe Mulrooney, William Scott, Lowery Smith, Steve Thomson, Livy Williams, Ray Williford, Stoneville, MS; Harold Sumner, Glynn Tillman, Tifton, GA; Gary Elzen, Weslaco, TX

Mission Statement: Develop application parameters and methodologies for efficient use and preservation of *Heliothis / Helicoverpa* control materials.

Objectives:

1. To evaluate application parameters for maximizing deposition on target crops and to develop methodologies for drift quantification and prediction.

2. To optimize application parameters for insecticides recommended for *Heliothis / Helicoverpa* control.

3. To monitor resistance and determine selectivity of new and current insecticides.

Approach Statement:

Deposition and drift from various application methods will be evaluated in field and laboratory studies using state-of-the-art instrumentation and application equipment. Insecticide efficacy studies will be conducted in small and large plot field experiments as well as in laboratory bioassays.

Cooperators:

University

Al Womac, University of Tennessee, Knoxville, TN

Private Industry

Chemical and spray equipment companies
Cotton producers

Communication:

Conference calls, e-mail, and meetings in conjunction with national meetings at least once a year.

Area 7. Efficient Use and Preservation of Insecticides

Research Approaches:	Year 1	Year 2	Year 3	Year 4	Year 5
1) Evaluate parameters to maximize deposition and develop and document drift mitigation methods.	Develop instruments and techniques for characterizing position of deposition sites and evaluating quantities of active material deposited.	Use instruments and techniques to document spatial distribution and pesticide distribution in the canopy.	Same as year 2 coupled with insect biology and insecticide activity.	Effect of droplet size, volume, and application parameters on deposition distribution.	Combine all data to develop a general understanding of the distribution of feeding sites in relation to insecticide location, stability and retention, movement of insects, and probability of insect contacting residue and dying from such contact.
	Design and construct iso-kinetic air samplers and test their suitability for drift quantification.	Evaluate sampling efficiency under controlled conditions; run field studies to relate drift plume leaving the field to application parameters.	Continue field studies and incorporate temporal aspects of drift into the measurements.	Same as year 3.	Optimize sampling techniques such that at least 90% of drift leaving field can be accounted for.
	Obtain drift models and become familiar with drift simulation; explore sensitivity of model outputs to changes in model inputs.	Use field studies to validate drift models; use drift simulations to determine optimum position for samplers under expected conditions.	Continue field studies.	Continue field studies.	Determine the feasibility of using available models to predict total drift; correlate drift plume sampling methods to model output.
	Develop and test a drop boom system for aerial application.	Evaluate boom system in field efficacy trials.	Continue as warranted.		
		Explore drift mitigation measures for high speed aircraft that can be used around highly sensitive areas.	Continue.	Continue.	Continue.

2) Optimize application parameters for H/H insecticides.	Develop insect sampling protocol for low populations; compare low, medium, and high rates of newer insecticides in large plot aerial spray tests.	Determine lowest effective rate of newer insecticides in large plot aerial spray tests; compare efficacy of fine, medium, and coarse droplet sizes of newer insecticide sprays applied by aircraft.	Determine optimum droplet size for aerial application of newer insecticides.	Evaluate lowest effective rate and optimum droplet size for aerial application of newer insecticides.	Same as Year 4
	Conduct spray table and field studies to determine optimum droplet size and spray rate for aerial applications of spinosad.	Conduct spray table and field studies to determine influence of adjuvants on deposition and efficacy of aerial applications of spinosad.	Review, summarize, and publish results of spinosad studies; initiate studies with newer candidate insecticides according to year 1 protocol.	Conduct studies with newer candidate insecticides according to year 2 protocol.	Review, summarize, and publish results from optimum application parameter studies.
		Evaluate effects of buffer zones on efficacy of selected insecticides.	Continue.	Continue.	
		Evaluate droplet size classifications and requirement effects on efficacy of selected insecticides.	Continue.	Continue.	Continue.
			Optimize application parameters of new or novel biological/chemical control agents for H/H.	Continue.	Continue.
	Develop or evaluate aerial and ground application technology for feeding attractant/stimulant/ insecticide formulations for adult control.	Refine aerial and ground application technology for adult control.	Evaluate aerial and ground application technology for adult control in small scale tests.	Evaluate aerial and ground application technology for adult control in large scale tests.	Evaluate aerial and ground application technology for adult control in large scale tests.

3) Monitor resistance and determine selectivity of insecticides.	Document residual toxicity of selected insecticides to H/H beneficial insects.		Collect predators (*Nabis, Zelus, Collops, Coleomegilla, Scymnus,* and *Posisus*) establish in culture, and determine residual toxicity of selected new and conventional insecticides to these species.		Complete studies in progress, publish results, and plan new research.
	Develop methodology for examining sublethal effects of insecticides on *G. punctipes* and *O. insidiosus* and begin concentration-mortality studies with spinosad and chlorfenapyr.	Continue concentration-mortality studies on *G. punctipes* and *O. insidiosus* to establish doses for sublethal effects. Complete studies of sublethal effects on *G. punctipes* and *O. insidiosus*.		Establish cultures of *Microplitis croceipes, Cotesia marginiventris,* and other parasitoids for studies of lethal and sublethal effects of insecticides.	
	Develop artificial diet for *G. punctipes*.	Measure spray deposition in specified buffer zones around treated fields to determine if insects receive sublethal dosages.	Continue.	Continue.	
	Screen old and new insecticide chemistry when mixed with feeding stimulants for adult control with emphasis on adult mortality and reproduction inhibition.	Conduct intensive laboratory evaluations of promising selective insecticides for effects on adult feeding behavior and physiology.	Evaluate selective insecticides in small scale field plots or field cages for adult control.	Conduct large scale test of selective insecticides for adult control.	Transfer selective insecticide technology for adult control to industry for commercial use.

APPENDIX A. PUBLICATIONS LIST, 1993-1997

Akins, D. C., T. L. Wagner, J. L. Willers, R. L. Olson and M. R. Williams. 1993. New graphical user interface for the rbWHIMS insect management expert system, pp. 1041-1043. *In* Proc. Beltwide Cotton Prod. Res. Conf., New Orleans, LA.

Alborn, H. T., T. C. J. Turlings, T. H. Jones, G. Stenhagen, J. H. Loughrin and J. H. Tumlinson. 1997. An elicitor of plant volatiles from beet armyworm oral secretion. Science 276: 945-949.

Alborn, H. T., W. J. Lewis and J. H. Tumlinson. 1995. Host-specific recognition kairomone for the parasitoid *Microplitis croceipes* (Cresson). J. Chem. Ecol. 21: 1697-1708.

Archer, T. L., B. R. Wiseman and A. J. Bockholt. 1994. Factors affecting corn earworm (Lepidoptera: Noctuidae) resistance in flour corn. J. Agric. Entomol. 11: 9-16.

Bali, G., A. K. Raina, T. G. Kingan and J. D. Lopez, Jr. 1996. Ovipositional behavior of newly colonized corn earworm, *Helicoverpa zea*, females and evidence for an oviposition stimulating factor of male origin. Ann. Entomol. Soc. Am. 89: 475-480.

Barry, B. D., B. R. Wiseman, F. M. Davis, J. L. Overman and J. A. Mihm. 1998. The benefits of insect resistance to the corn industry and the general public. 1994 ESA Symposium. ESA Thomas Say Misc. Pub. (Accepted).

Beerwinkle, K. R., T. N. Shaver, P. D. Lingren and J. R. Raulston. 1996. Free-choice olfactometer bioassay system for evaluating the attractiveness of plant volatiles to adult *Helicoverpa zea*. Southwest. Entomol. 21: 395-405.

Beerwinkle, K. R., J. D. Lopez, Jr., D. Cheng, P. D. Lingren and R. W. Meola. 1995. Flight potential of feral *Helicoverpa zea* (Lepidoptera:Noctuidae) males measured with a 32-channel, computer-monitored, flight mill system. Environ. Entomol. 24: 1122-1130.

Beerwinkle, K. R., J. D. Lopez, Jr., P. G. Schleider and P. D. Lingren. 1995. Annual patterns of aerial insect densities at altitudes from 500 to 2400 meters in East-Central Texas indicated by continuously-operating vertically-oriented radar. *In* J. R. Raulston, and J. E. Slosser [eds.], Noctuids: Recent Advances in Detection and Migration in the U. S. Southwest. Entomol. Suppl. No. 18: 63-79.

Beerwinkle, K. R., J. D. Lopez, Jr., J. A. Witz, P. G. Schleider, R. S. Eyster and P. D. Lingren. 1994. Seasonal radar and meteorological observations associated with nocturnal insect flight at altitudes to 900 Meters. Environ. Entomol. 23: 676-683.

Bell, M. R. and D. D. Hardee. 1995. Tobacco budworm and cotton bollworm: Methodology for virus production and application in large-area management trials, pp. 857-859. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bell, M. R. and D. D. Hardee. 1994. Development of an area-wide program for management of *Heliothis/Helicoverpa* (Lepidoptera: Noctuidae) through early season application of an entomopathogenic virus: 1992 field trial. J. Entomol. Sci. 29: 192-200.

Bell, M. R. and D. D. Hardee. 1994. Tobacco budworm: possible use of various entomopathogens in large area pest management, pp. 1168-1171. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Bell, M. R. and D. D. Hardee. 1993. Development of an area-wide program for management of *Heliothis/Helicoverpa* through early-season application of an entomopathogenic virus - 1992 field trial, pp. 865-868. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Berg, B. G., J. H. Tumlinson and H. Mustaparta. 1995. Chemical communication in Heliothine moths, IV. Receptor neuron responses to pheromone compounds and formate analogues in the male tobacco budworm moth *Heliothis virescens*. J. Comp. Physiol. A. 177: 527-534.

Blackburn, M. B., R. M. Wagner, J. Shabanowitz, J. P. Kochansky, D. F. Hunt and A K. Raina. 1995. The isolation and identification of three diuretic kinins from the abdominal ventral nerve cord of adult *Helicoverpa zea*. J. Insect Physiol. 41: 723-730.

Bondari, K. and B. R. Wiseman. 1997. Genetic basis of silk resistance (antibiosis) to the corn earworm in six crosses of maize lines: Statistical methodology, pp. 127-131. *In* J. A. Mihm [ed.], Insect Resistant Maize: Recent Advances and Utilization. Proc. of an International Symposium held at the International Maize and Wheat Improvement Center (CIMMYT), 27 November - 3 December 1994. Mexico, D.F.: CIMMYT. 302 p.

Brandt, S. L., T. A. Coudron, D. Jones and A. Raqib. 1995. Regulation of storage protein production in envenomated host larvae parasitized by Euplectrus spp. (Hymenoptera: Eulophidae). 5th Pan American Symposium on Animal, Plant, and Microbial Toxins. Abstr. #195, p 43.

Brown, Robert L., P. J. Cotty, T. E. Cleveland and N. W. Widstrom. 1993. Living maize embryo influences accumulation of Aflatoxin in maize kernels. Journal of Food Protection 56: 967-971.

Bryant, V. M., Jr., P. D. Lingren, M. W. Pendleton and G. D. Jones. 1994. Entomopalynological techniques used in the search for migratory and feeding habits of adult corn earworm, celery looper, and cabbage looper moths. Palynology 18: 239.

Buckner, J. S., M. C. Mardaus and D. R. Nelson. 1996. Cuticular lipid composition of *Heliothis virescens* and *Helicoverpa zea* pupae. Comp. Biochem. Physiol. 114B: 207-216.

Bultman, T. L., K. L. Borowicz, R. M Schneble, T. A. Coudron and I. P. Bush. 1997. Effect of a fungal endophyte on the growth and survival of two *Euplectrus* parasitoids. OIKOS 78: 170-176.

Byrne, P. F., M. D. McMullen, M. E. Snook, T. A. Musket, J. M. Theuri, N. W. Widstrom, B. R. Wiseman and E. H. Coe. 1996. Quantitative trait loci and metabolic pathways: Genetic control of the concentration of maysin, a corn earworm resistance factor, in maize silks. Proc. Natl. Acad. Sci. Agricultural Sciences 93: 8820-8825.

Byrne, P. F., L. L. Darrah, M. E. Snook, B. R. Wiseman, N. W. Widstrom, D. J. Moellenbeck and B. D. Barry. 1996. Maize silk-browning, maysin content, and antibiosis to the corn earworm, *Helicoverpa zea* (Boddie). Maydica 41: 13-18.

Byrne, P. F., M. D. McMullen, M. E. Snook, B. R. Wiseman, T. A. Musket, J. M. Theuri, N. W. Widstrom and E. H. Coe. 1997. Identification of maize chromosome regions associated with antibiosis to corn earworm larvae (Lepidoptera: Noctuidae). J. Econ. Entomol. 90:. (Accepted)

Byrne, P. F., M. D. McMullen, B. R. Wiseman, M. E. Snook, T. A. Musket, J. M. Theuri, N. W. Widstrom and E. H. Coe. 1997. QTL analysis of silk maysin concentration and corn earworm antibiosis in maize. Crop Science. (Accepted).

Byrne, P. F., L. L. Darrah, D. J. Moellenbeck, B. D. Barry, M. E. Snook, B. R. Wiseman and N. W. Widstrom. 1994. Silk browning, maysin content, and corn earworm resistance. Maize Genet. Coop. Newsletter 68: 35.

Byrne, P. F., M. D. McMullen, M. E. Snook, T. Musket, N. W. Widstrom and B. R. Wiseman. 1996. Quantitative genetic analysis of loci controlling synthesis of maysin, a corn earworm resistance factor, in maize silks. Proc. Natl. Acad. Sci. USA. Agricultural Sciences 93: 8820-8825.

Calkins, C. O., R. M. Faust, J. R. Coppedge, J. F. Brunner, L. D. Chandler, D. D. Hardee and M. R. Bell. 1997. Areawide IPM as a tool for the future. Proc. 3rd National IPM Symposium (In Press).

Carpenter, J. E. and A. C. Bartlett. Genetic Approaches to Managing Arthropod Pests. *In*: J. Ruberson [ed.] Handbook on Pest Management, New York, Marcel Dekker, Inc. (Accepted for publication)

Carpenter, J. E., Hidrayani, Novri Nelly and B. G. Mulinix. 1997. Effect of substerilizing doses of radiation on sperm precedence in fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). J. Econ. Entomol. 90: 444-448.

Carpenter, J. E., Hidrayani and W. Sheehan. 1996. Compatibility of F_1 sterility and a parasitoid, *Cotesia marginiventris* (Hymenoptera: Braconidae), for managing *Spodoptera exigua* (Lepidoptera: Noctuidae): acceptability and suitability of hosts. Fl Entomol. 79(3): 289-295.

Carpenter, J. E., C. M. Mannion and Hidrayani. 1996. Potential of combining inherited sterility and parasitoids for managing lepidopteran pests. Proc. of FAO/IAEA First Research Co-ordination Meeting on "Evaluation of Population Suppression by Irradiated Lepidoptera and Their Progeny", Jakarta, Indonesia, 24-28 April 1995. IAEA-D4-RC-561, pp. 273-283.

Carpenter, J. E. 1995. *Ichneumon promissorius* (Erichson) (Hymenoptera: Ichneumonidae): Factors affecting fecundity, oviposition, and longevity. J. Entomol. Sci. 30: 279-286.

Carpenter, J. E. and L. D. Chandler. 1994. Effects of sublethal doses of two insect growth regulators on *Helicoverpa zea* (Lepidoptera: Noctuidae) reproduction. J. Entomol. Sci. 29: 428-435.

Carpenter, J. E., S. D. Pair and G. P. Fitt. 1994. *Ichneumon promissorius* (Hymenoptera: Ichneumonidae): Development on North American hosts. J. Econ. Entomol. 87(4): 929-932.

Carpenter, J. E. 1993. Integration of inherited sterility and other pest management strategies for *Helicoverpa zea*: Status and potential. Proceedings of an Intl. symposium on management of insect pests: Nuclear and related molecular and genetic techniques. Jointly organized by the Intl. Atomic Energy Agency and The Food and Agric. Organization of the U. N., Vienna, 19-23 October 1992. IAEA-SM-327/35, pp. 363-370.

Carpenter, J. E. and H. R. Gross. 1993. Suppression of feral *Helicoverpa zea* (Lepidoptera: Noctuidae) populations following the infusion of inherited sterility from released substerile males. Environ. Entomol. 22: 1084-1091.

Chandler, L. D., J. L. Robertson and H. K. Preisler. 1995. Effects of combinations of chlorpyrifos and cypermethrin on mortality of corn earworm and fall armyworm (Lepidoptera: Noctuidae) larvae. Canadian Entomol. 127: 25-32.

Chandler, L. D., H. R. Sumner and B. G. Mullinix. 1994. Assessment of irrigation-related insecticide application methods for control of lepidopteran pests of sweet corn. J. Econ. Entomol. 87: 212-219.

Chandler, L. D., H. R. Sumner and G. A. Herzog. 1993. Management of bollworm in sprinkler irrigated cotton: Residual activity of four classes of insecticides applied via chemigation, pp. 1614-1616. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Chen, Q., A. H. McIntosh, Z. Yu, H. Hong, C. L. Goodman, J. J. Grasela and C. M. Ignoffo. 1993. The replication of *Autographa californica* baculovirus (AcMNPV) in two lepidopteran cell lines grown in serum-free media. J. Invertebr. Pathol. 62:216-219.

Chun, J., C. L. Goodman, W. C. Rise, A. H. McIntosh, G. M. Chippendale and K. R. Schubert. 1994. *Pentaclethra macroloba* seed effect of larval growth, cell viability, and midgut enzyme activity of *Helicoverpa zea* (Lepidoptera: Noctuidae). J. Econ. Entomol. 87(b):1754-1760.

Clemens, C. G. 1996. Effects of feeding stimulant and insecticide mixtures on feeding response and mortality of adult male corn earworm, *Helicoverpa zea* (Boddie) (Lepidoptera:Noctuidae). M.S. Thesis, Texas A&M University, College Station.

Cortesero, A. M., C. M. DeMoraes, J. O. Stapel, J. H. Tumlinson and W. J. Lewis. 1997. Comparisons and contrasts in host foraging strategies of two larval parasitoids with different degrees of host specificity. J. Chem. Ecol. 23: 1589-1606.

Coudron, T. A., S. L. Brandt and A. Raqib. 1997. Comparison of the response of *Heliothis virescens* to parasitism by *Euplectrus comstockii* and *Euplectrus plathypenae*. Comp. Biochem. Physiol. 116B:197-202.

Coudron, T. A. and S. L. Brandt. 1996. Developmental arrestant isolated from the venom of *Euplectrus comstockii*. Entomol. Soc. Am. Sect. B. Abstr 209, pp. 33-34.

Coudron, T. A. and S. L. Brandt. 1996. Characteristics of the developmental arrestant in the venom of the ectoparasitoid wasp *Euplectrus comstockii*. Toxicon 34: 1431-1441.

Coudron, T. A., W. C. Rice, M. R. Ellersieck and R. E. Pinnell. 1995. Mediated pathogenicity of the baculovirus HzSNPV by the venom from *Euplectrus comstockii* (Hymenoptera: Eulophidae). Biological Control 5: 92-98.

Coudron, T. A. 1995. Endocrinologically active venom proteins of ectoparasitic wasps. 5th Pan American Symposium on Animal, Plant and Microbial Toxins. Abstr 103, p 24.

Coudron, T. A. 1994. Biological regulators in insect pest management. North Central Branch Entomol. Soc. Of Am. Abstr. p 20.

Coudron, T. A., D. Jones and G. Jones. 1994. Premature production of late larval storage proteins in larvae of *Trichoplusia ni* parasitized by *Euplectrus comstockii*. Arch. Insect Biochem. Physiol. 26:97-109.

Davis, F. M., B. R. Wiseman, W. P. Williams and N. W. Widstrom. 1996. Insect colony, planting date, and plant growth stage effects on screening maize for leaf-feeding resistance to fall armyworm (Lepidoptera: Noctuidae). Florida Entomol. 79(3): 317-328.

DeVault, J. D., O. A. Johnson, R. A. Leopold, I. C. McDonald and K. J. Hughes. 1997. Partial purification of a phenol oxidase (Tyrosinase) activity from adult tobacco budworm (*Heliothis virescens*). Biochem. Biophys. Res. Comm. (In Press).

DeVault, J. D., K. J. Hughes, O. A. Johnson and S. K. Narang. 1996. Biotechnology and new integrated pest management approaches. Bio/Technology. 14: 46-49.

DeVault, J. D., K. J. Hughes, R. A. Leopold, O. A. Johnson and S. K. Narang. 1996. Gene transfer into corn earworm embryos. Genome Res. 6: 571-579.

DeVault, J. D. and S. K. Narang. 1994. Transposable elements in Lepidoptera: hobo-like transposons in *Heliothis virescens* and *Helicoverpa zea*. Biochem. Biophys. Res. Comm. 203: 169-175.

Dicko, I. O. and R. E. Lynch. 1995. Effectiveness of soil-applied insecticides against foliage-and pod-feeding arthropod pests in Burkino Faso. Int. Arachis Newsletter 15: 60-62.

El-Sayed, G. N., C. M. Ignoffo, T. D. Leathers and S. C. Gupta. 1993. Cuticular and non-cuticular substrate influence on expression on cuticle-degrading enzymes from conidia of an entomopathogenic fungus, *Nomuraea rileyi*. Mycopathologia 122:79-87.

El-Sayed, G. N., C. M. Ignoffo, T. D. Leathers and S. C. Gupta. 1993. Insect cutidle and yeast extract effects on germination, growth, and production of hydrolytic enzymes by *Nomuraea rileyi*. Mycopathologia 122:143-147.

El-Sayed, G. N., C. M. Ignoffo, T. D. Leathers and S. C. Gupta. 1993. Effects of cuticle source and concentration on expression of hydrolytic enzymes by an entomopathogenic fungus, *Nomuraea rileyi*. Mycopathologia 122:149-152.

Elzen, G. W. 1997. Evaluation of tolerance to insecticides in tobacco budworm and bollworm populations, 1996. *In* Proc. Beltwide Cotton Prod. Res. Conf., Memphis, TN.

Elzen, G. W. 1997. Changes in resistance to insecticides in tobacco budworm populations in Mississippi, 1993-1995. Southwest. Entomol. 22: 61-72.

Elzen, G. W., L. C. Adams and D. D. Hardee. 1997. Evaluation of tolerance to insecticides in tobacco budworm and bollworm populations, 1996. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Elzen, G. W. 1996. Changes in tolerance to insecticides in tobacco budworm populations, 1995, pp. 779-884. *In* Proc. Beltwide Cotton Prod. Res. Conf., Memphis, TN.

Elzen, G. W. 1995. Trends in *Heliothis* resistance, pp. 964-967. *In* Proc. Beltwide Cotton Prod. Res. Conf., Memphis, TN.

Elzen, G. W. 1994. Characterization of *Heliothis virescens* (F.) resistance to insecticides in Mississippi in 1992: Multiple vs. cross-resistance. Southwest. Entomol. 19: 219-227.

Elzen, G. W., S. H. Martin, J. B. Graves and B. R. Leonard. 1994. Resistance within classes of insecticides in tobacco budworm, pp. 764-768. *In* Proc. Beltwide Prod. Res. Conf., Memphis, TN.

Elzen, G. W., S. Martin, B. R. Leonard and J. B. Graves. 1994. Inheritance, stability, and reversion of insecticide resistance in tobacco budworm (Lepidoptera: Noctuidae) field populations. J. Econ. Entomol. 87: 551-558.

Elzen, G. W. 1993. Tobacco budworm insecticide resistance in the Mississippi Delta, pp. 25-27. *In* Proc. Beltwide Cotton Prod. Res. Conf., Memphis, TN.

Elzen, G. W., S. H. Martin and J. B. Graves. 1993. Characterization of tobacco budworm resistance: Seasonal aspects and synergism, pp. 1024-1028. *In* Proc. Beltwide Cotton Prod. Res. Conf., Memphis, TN.

Elzen, G. W. 1993. Evaluation of insecticides for control of lepidopterous pests, 1992. Insecticide and Acaricide Tests 18: 221.

Gazit, Y., W. J. Lewis, and J. H. Tumlinson. 1996. Arrestment of *Telemonus remus* (Hymenoptera: Scelionidae) by a kairomone associated with eggs of its host, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Biological Control 6: 283-290.

Goodman, C. L., M. H. Greenstone and M. K. Stuart. 1997. Monoclonal antibodies to vitellins of bollworm and tobacco budworm (Lepidoptera:Noctuidae): biochemical and ecological implications. Ann. Ent. Soc. Amer. 90: 83-90.

Goodman, C. L. and A. H. McIntosh. 1994. Production of baculoviruses for insect control using cell culture. pp. 33-56. *In* K. Maramorosch and A. H. McIntosh [eds.], Insect Cell Biotechnology. CRC Press, Inc., Boca Raton, Ann Arbor, Boston, London.

Gould, F., A. Anderson, A. Jones, D. Sumerford, D. G. Heckel, J. D. Lopez, Jr., S. Micinski and R. Leonard. 1997. Initial frequency of alleles for resistance to *Bacillus thuringiensis* toxins in field populations of *Heliothis virescens*. Proc. Natl. Acad. Sci. USA. 94: 3519-3523.

Grasela, J. J. and A. H. McIntosh. 1997. *In vitro* and *in vivo* host range of *Anticarsia gemmatalis* multiple nuclear polyhedrosis viris. In Vitro Cell. Dev. Biol. (In Press)

Graves, J. B., G. W. Elzen, M. B. Layton, R. H. Smith and M. L. Wall. 1995. Budworm/bollworm management: Insecticide resistance and population trends in the mid-south. pp. 136-140. *In* Proc. Beltwide Cotton Prod. Res. Conf., Memphis, TN.

Gross, H. R., C. E. Rogers and J. E. Carpenter. 1996. Development of *Archytas marmoratus* (Diptera: Tachinidae) reared in *Galleria mellonella* larvae (Lepidoptera: Pyralidae) feeding on selected diets. Biological Control 6: 158-163. Article No. 0020.

Guo, B., J. S. Russin, T. E. Cleveland, R. L. Brown and N. W. Widstrom. 1995. Wax and cutin layers in maize kernels associated with resistance to Aflatoxin production by *Aspergillus flavus*. J. Food Protection 58: 296-300.
Guo, B., J. S. Russin, R. L. Brown, T. E. Cleveland and N. W. Widstrom. 1995. Resistance to Aflatoxin contamination in corn as influenced by relative humidity and kernel germination. J. Food Protection. 59(3): 276-281.

Hamm, J. J. and J. E. Carpenter. 1997. Compatibility of nuclear polyhedrosis viruses and inherited sterility for control of corn earworm and fall armyworm (Lepidoptera: Noctuidae). J. Entomol. Sci. 32(2): 148-153.

Hamm, J. J., J. E. Carpenter and E. L. Styer. 1996. Oviposition day effect on incidence of agonadal progeny of *Helicoverpa zea* (Lepidoptera: Noctuidae) infected with a virus. Ann. Entomol. Soc. Am. 89(2): 266-275.

Hamm, J. J. and L. D. Chandler. 1993. Use of Elcar for early-season suppression of bollworm on corn and implications for bollworm control on cotton, pp. 861-864. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Haney, P. B., W. J. Lewis, J. R. Ruberson and S. Phatak. 1996. Continued studies of insect population dynamics in cromson clover and refugia/cotton systems, Part II: Pitfall trap sampling, pp. 1115-1119. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Haney, P. B., W. J. Lewis and W. R. Lambert. 1996. Cotton production and the boll weevil in Georgia-History, cost of control and benefits of eradication. University of Georgia-USDA Research Bulletin 42: 48 p.

Haney, P. B., O. J. Stapel, D. J. Waters, W. J. Lewis, S. K. Diffie and J. R. Ruberson. 1995. Dynamics of insect populations in a reduced-tillage, crimson clover/cotton system Part II: Pitfall survey, pp. 817-821. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Hardee, D. D. 1997. Use of novel chemicals in IPM. Recent Res. Devel. in Entomol. 1: 15-22.

Hardee, D. D. and M. R. Bell. 1997. Area-wide management of bollworm/budworm with pathogens -- results of six year project and projections for the future. Recent Res. Devel. in Entomol. 1: 105-114.

Hardee, D. D. and W. W. Bryan. 1997. Influence of *Bt*-transgenic and nectariless cotton on insect populations, with special emphasis on the tarnished plant bug (Heteroptera: Miridae). J. Econ. Entomol. (In Press).

Hardee, D. D. and G. A. Herzog. 1997. 50th Annual Conference Report on Cotton Insect Research and Control. *In* Proc. Beltwide Cotton Prod. Res. Conf., (In Press).

Hardee, D. D. and E. B. Mitchell. 1997. Boll weevil, *Anthonomus grandis* Boheman: A summary of research on behavior as affected by chemical communication. *In* A Centennial Symposium on the Cotton Boll Weevil. USDA-ARS (In Press).

Hardee, D. D., D. A. Streett, L. C. Adams and G. W. Elzen. 1997. Resistance monitoring in *Bt* cotton: First year observations. *In* Proc. Beltwide Cotton Prod. Res. Confs. (In Press).

Hardee, D. D. and M. L. Laster. 1996. Current status of backcross sterility in *Heliothis virescens* (F.) - a progress report. Southwest. Entomol. 21: 85-100.

Hardee, D. D. 1996. Crop protection products outlook -- insecticides and fungicides. Proc. Beltwide Cotton Prod. Res. Confs., pp. 29-31.

Hardee, D. D. 1996. Resistance management in the Mid South -- cotton aphid: Current status as a pest of cotton. Proc. Cotton Inc. Seminar on Resistance, Cotton Inc., Raleigh, NC.

Hardee, D. D. and M. R. Bell. 1996. Six years of area-wide management of bollworm/ budworm with pathogens -- what does it mean and where do we go from here. Proc. Beltwide Cotton Prod. Res. Confs., pp. 897-902.

Hardee, D. D. and M. R. Bell. 1996. Area-wide management of *Heliothis/Helicoverpa* in the delta of Mississippi - 1994 program. *In* Challenging the Future. Proc. World Cotton Res. Conf., Brisbane, Australia, pp. 434-436.

Hardee, D. D. and G. A. Herzog. 1996. 49th Annual Conference Report on Cotton Insect Research and Control. Proc. Beltwide Cotton Prod. Res. Confs., pp. 643-669.

Hardee, D. D. and M. L. Laster. 1996. Current status of backcross sterility in *Heliothis virescens* (F.) -- a progress report. Southwest. Entomol. 21: 85-100.

Hardee, D. D., A. A. Weathersbee, III, J. M. Gillespie, G. L. Snodgrass and A. R. Quisumbing. 1996. Performance of trap designs, lures, and kill strips for the boll weevil (Coleoptera: Curculionidae). J. Econ. Entomol. 89: 170-174.

Hardee, D. D. 1995. Future changes - Bt cotton, boll weevil eradication, insecticide resistance. Proc. Symp. on Tarnished Plant Bug, Mississippi State University, Stoneville, MS.

Hardee, D. D. 1995. Resistance management in the mid south -- cotton aphid: current status as a pest of cotton. Proc. Cotton Incorporated Crop Management Seminar, Memphis, TN.

Hardee, D. D. and G. A. Herzog. 1995. 48th Annual Conference Report on Cotton Insect Research and Control. Proc. Beltwide Cotton Prod. Res. Confs., pp. 725-744.

Hardee, D. D. and R. I. Carruthers. 1994. Section E - Crop Management Systems and Host Plant Resistance, pp. 116-133. *In* Henneberry, T. J., and N. C. Toscano (eds.), Sweetpotato Whitefly: 1994 Supplement to the Five-Year National Research and Action Plan, USDA-ARS.

Hardee, D. D. and G. A. Herzog. 1994. 47th Annual Conference Report on Cotton Insect Research and Control. Proc. Beltwide Cotton Prod. Res. Confs., pp. 717-740.

Hardee, D. D., M. T. Smith, A. A. Weathersbee, III and G. L. Snodgrass. 1994. Sampling of the cotton aphid (Homoptera: Aphididae) in cotton. Southw. Entomol. 19: 33-44.

Hardee, D. D., A. A. Weathersbee, III and M. T. Smith. 1994. Workshop: Management of aphids and whiteflies - biological control of the cotton aphid. Proc. Beltwide Cotton Prod. Res. Conf., pp. 132-133.

Hardee, D. D. 1993. Resistance in aphids and whiteflies - principles and keys to resistance management. Proc. Beltwide Cotton Prod. Confs., pp. 20-23.

Hardee, D. D. and J. M. Ainsworth. 1993. Cotton aphid (Homoptera: Aphididae): Effect of in-furrow insecticides on pesticide resistance. J. Econ. Entomol. 86: 1026-1029.

Hardee, D. D. and G. A. Herzog. 1993. 46th Annual Conf. Rept. on Cotton Insect Research and Control. Proc. Beltwide Cotton Prod. Res. Confs., pp. 635-654.

Hardee, D. D. and G. G. Still. 1993. Section E - Crop Management Systems and Host Plant Resistance. *In* Henneberry, T. J., and N. C. Toscano. Sweetpotato Whitefly: 1993 Supplement to the Five-Year National Research and Action Plan, USDA-ARS-112, pp. 116-133.

Hardee, D. D., M. T. Smith and A. A. Weathersbee, III. 1993. Sampling of the cotton aphid (*Aphis gossypii* Glover). Proc. Beltwide Cotton Prod. Res. Confs., pp. 738-740.

Hardin, J. M., J. L. Willers and T. L. Wagner. 1996. Non-Parametric multiple comparisons of survivorship distributions for Arthropods. J. Econ. Entomol. 89: 715-721.

Harrison, W. W., D. A. Herbert and D. D. Hardee. 1993. Effect of parasitoid and host age on oviposition and emergence of *Microplitis croceipes* (Hymenoptea: Braconidae), an endoparasitoid of *Helicoverpa zea* (Lepidoptera: Noctuidae). J. Entomol. Sci. 28: 343-349.

Hendricks, D. E., D. W. Hubbard and D. D. Hardee. 1995. Occurrence of beet armyworm moths in the lower Mississippi River Delta as indicated by numbers caught in traps in 1994. Southwest. Entomol. 20: 157-164.

Hendricks, D. E., D. W. Hubbard and D. D. Hardee. 1995. Occurrence of beet armyworm moths in cotton-growing areas of the lower Mississippi River Delta as indicated by numbers caught in pheromone traps from April to November 1994. Proc. Beltwide Cotton Prod. Res. Conf., pp. 802-804.

Herzog, G. A., D. D. Hardee and M. R. Williams. 1996. Highlights of the 49th Annual Cotton Insect Research and Control Conference. Proc. Beltwide Cotton Prod. Res. Confs., pp. 669-670.

Herzog, G. A., D. D. Hardee and M. R. Williams. 1995. Highlights of the 48th Annual Cotton Insect Research and Control Conference. Proc. Beltwide Cotton Prod. Res. Conf., pp. 744-745.

Herzog, G. A., D. D. Hardee and M. R. Williams. 1994. Highlights of the 47th Annual Cotton Insect Research and Control Conference. Proc. Beltwide Cotton Prod. Res. Conf., pp. 741-742.

Herzog, G. A. and D. D. Hardee. 1993. Highlights of the 46th Annual Cotton Insect Research and Control Conference. Proc. Beltwide Cotton Prod. Res. Confs., pp. 661-662.

Heilmann, L.J., J.D. DeVault, R. A. Leopold and S.K. Narang. 1993. Improvement of natural enemies for biological control: A genetic engineering approach. In: A*Genetic Applications to Arthopods of Biological Control Significance@.* (Eds. S.K. Narang, A.C. Bartlett and R.M. Faust). CRC Press, Boca Raton, Fl. pp. 167-189.

Heilmann, L.J., J.D. DeVault, R. A. Leopold and S.K. Narang. 1993. Improvement of natural enemies for biological control: A genetic engineering approach. In: A*Genetic Applications to Arthopods of Biological Control Significance@.* (Eds. S.K. Narang, A.C. Bartlett and R.M. Faust). CRC Press, Boca Raton, Fl. pp. 167-189.

Hughes, K.J., S.K. Narang, R.A. Leopold, O.A. Johnson and J.D. DeVault. 1997. Electroporation as an alternative to microinjection of plasmid DNA into Bollworm embryos. Ann. Entomol. Soc. Amer. 90: 107-113.

Hughes, K.J., S.K. Narang, R.A. Leopold, O.A. Johnson and J.D. DeVault. 1996. Genetically altering insects: Promise, prospect and limitations. In: ACS Symposium, A*Molecular Genetics and Evolution of Pesticide Resistance@.* (Ed. T.M. Brown) pp. 221-228.

Ignoffo, C. M. and C. Garcia. 1997. Effect of viral concentration and body weight on mortality of *Trichoplusia ni* larvae exposed to wild-type or recombinant strains of the nuclear polyhedrosis virus of *Autographa californica.* Environ. Entomol. (Accepted 2/97)

Ignoffo, C. M. and C. Garcia. 1996. Simulated sunlight-UV sensitivity of experimental dust formulations of the nuclear polyhedrosis virus of *Helicoverpa/Heliothis.* J. Invetebr. Pathol. 67:192-194.

Ignoffo, C. M. and C. Garcia. 1996. Mortality and feeding of late instar *Trichoplusia ni* larvae fed a wild-type or recombinant strain of the nuclear polyhedrosis virus of *Autographa californica*: AcMNPV. J. Invertebr. Pathol. 68:191-193.

Ignoffo, C. M. and C. Garcia. 1996. Rate of larval lysis and yield and activity of inclusion bodies harvested from *Trickoplusia ni* larvae fed a wild-type or recombinant isolate of nuclear polyhedrosis virus of *Autographa californica*. J. Invertebr. Pathol. 68:196-198.

Ignoffo, C. M. and C. Garcia. 1995. Aromatic/heterocyclic amino acids effects on the simulated sunlight-UV inactiviation of inclusion bodies of the singly-enveloped *Heliothis/Helicoverpa* baculovirus. Environ. Entomol. 24:480-482.

Ignoffo, C. M. 1995. Sensitivity of larvae of *Helicoverpa (Heliothis) zea* to intrahemocoelic injections of invertebrate and vertebrate toxins. J. Invertebr. Pathol. 66:97-98.

Ignoffo, C. M., C. Garcia, D. Zuidema and J. M. Vlak. 1995. Relative *in vivo* activity simulated sunlight-UV stability of inclusion bodies of a wild=type and an engineered polyhedral envelope-negative isolate of the nucleopolyhedrosis virus of *Autographa californica*. J. Invertebr. Pathol. 66:212-213.

Ignoffo, C. M. and C. Garcia. 1994. Antioxidant and oxidative enzyme effects on the inactivation of inclusion bodies of the *Heliothis* baculovirus by simulated sunlight - UV. Environ. Entomol. 23:1025-1029.

Jones, G. D. and J. D. Lopez, Jr. 1997. Pollen analyses of the crop of adult corn earworms. *In* New Developments in Palynomorph Sampling, Extraction, and Analysis. American Association of Stratigraphic Palynologists, Dallas, Texas (in press).

Jones, G. D. and J. R. Coppedge. 1996. Pollen Contamination of *Citrus* Nectar. Palynology 20: 242.

Jones, G. D., V. M. Bryant, Jr., M. M. Lieux, S. D. Jones and P. D. Lingren. 1995. Pollen of the southeastern United States: with emphasis on melissopalynology and entomopalynology. Am. Assoc. Stratigr. Palynol. Contrib. Ser. #30. Dallas, TX.

Kaas, J. P., S. B. Ramaswamy and G. W. Elzen. 1993. Behavioral time budget and periodicity exhibited by Microplitis croceipes in field cages with *Heliothis virescens* on spring host plants. Entomophaga. 38: 143-154.

Kanga, L. H. B., F. W. Plapp, Jr., B. F. McCutchen, R. D. Bagwell and J. D. Lopez, Jr. 1996. Tolerance to cypermethrin and endosulfan in field populations of the bollworm (Lepidoptera:Noctuidae) from Texas. J. Econ. Entomol. 89: 583—589.

Kanga, L. H. B., F. W. Plapp, Jr., G. W. Elzen, M. L. Wall and J. D. Lopez, Jr. 1995. Monitoring for resistance to organophosphorus, carbamate, and cyclodiene insecticides in tobacco budworm adults (Lepidoptera: Noctuidae). J. Econ. Entomol. 88: 1144-1149.

Kanga, L. H. B., F. W. Plapp, Jr., M. L. Wall and G. W. Elzen. 1995. A four year study of resistance to organophosphorus, carbamate, and cyclodiene insecticides in the tobacco budworm in Texas and Arkansas. Southwest. Entomol. 20: 237-346.

Kanga, L. H. B., F. W. Plapp, Jr., M. L. Wall, G. W. Elzen and J. Lopez. 1994. Resistance monitoring and mechanisms in the tobacco budworm to organophosphate, carbamate, and cyclodiene insecticides, pp. 810-815. In Proc. Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

Kanga, L. H. B., F. W. Plapp, Jr., M. L. Wall and G. W. Elzen. 1993. Monitoring for resistance to nonpyrethroid insecticides in the tobacco budworm, pp. 802-803. In Proc. Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.

King, E. G., R. J. Coleman, L. Wood, L. Wendel, S. Greenberg, A. Scott, J. Roberson and D. D. Hardee. 1995. Suppression of the boll weevil in commercial cotton by augmentative releases of a wasp parasite, *Catolaccus grandis*. Proc. Beltwide Cotton Prod. Res. Conf. Addendum, pp. 26-30.

Kingan, T. G., W. M. Bodnar, A. K. Raina, J. Shabanowitz and D. F. Hunt. 1995. The loss of female sex pheromone after mating in the corn earworm moth, *Helicoverpa zea*: Identification of male pheromonostatic peptide. *Proc. Natl. Acad. Sci.* USA. 92: 5082-5086.

Kingan, T. G. and A. K. Raina. 1994. Pheromonostatic peptide used to disrupt mating of the corn earworm, *Helicoverpa zea.* U.S. Patent No. 5,344,821 (Patent).

Kingan, T. G., P. A. Thomas-Laemont and A. K. Raina. 1993. Male accessory gland factors elicit change from Avirgin@ to Amated@ behaviour in the female corn earworm moth, *Helicoverpa zea. J. Exp. Biol.* 183: 61-76.

Lambert, W. A., G. A. Herzog, J. R. Ruberson and W. J. Lewis. 1994. Tobacco budworm and bollworm managment strategies in the absence of the boll weevil. Proc. Beltwide Cotton Conv. 2: 794-795.

Laster, M. L., D. D. Hardee and J. C. Schneider. 1996. *Heliothis virescens* (Lepidoptera: Noctuidae) influence by sterile backcross releases on suppression. Southw. Entomol. 21: 433-444.

Laster, M. L. and D. D. Hardee. 1995. Intermating compatibility between North American *Helicoverpa zea* and *Heliothis armigera* (Lepidoptera: Noctuidae) from Russia. J. Econ. Entomol. 88: 77-80.

Laster, M. L. 1995. *Proboscidea louisianica*: An unreported host of *Heliothis virescens* (Lepidoptera: Noctuidae). J. Entomol. Sci. 30: 429-433.

Laster, M. L. and D. D. Hardee. 1995. Intermating compatibility between North American *Helicoverpa zea* and *Heliothis armigera* (Lepidoptera: Noctuidae) from Russia. J. Econ. Entomol. 88: 77-80.

Laster, M. L., D. D. Hardee and J. C. Schneider. 1994. Release of sterile backcross moths during 1993 in a pilot program to control the tobacco budworm. Proc. Beltwide Cotton Prod. Res. Conf., pp. 925-927.

Laster, M. L., D. D. Hardee and J. L. Roberson. 1993. Emergence of male-sterile *Heliothis virescens* (Lepidoptera: Noctuidae) backcross moths at a central release point and their resulting spatial distribution. J. Entomol. Sci. 28: 241-248.

Laster, M. L., D. D. Hardee and J. C. Schneider. 1993. A pilot program to control the tobacco budworm, *Heliothis virescens* (F.), by releasing sterile backcross insects into the natural population. Proc. Beltwide Cotton Prod. Res. Confs., pp. 874-876.

Laster, M. L., D. D. Hardee and J. L. Roberson. 1993. Emergence of male-sterile *Heliothis virescens* (Lepidoptera: Noctuidae) backcross moths at a central release point and their resulting spatial distribution. J. Entomol. Sci. 28: 241-248.

Laster, M. L., D. D. Hardee and J. C. Schneider. 1993. A pilot program to control the tobacco budworm, *Heliothis virescens* (F.), by releasing sterile backcross insects into the natural population, pp. 874-876. *In* Proc. Beltwide Cotton Prod. Res. Conf.

Leopold, R.A. 1997. Cold storage of insects for integrated pest management. In: *ALethal Temperatures in Integrated Pest Management.@* (Eds. G.J. Hallman and D.L. Denlinger) Westview Press. (In Press).

Leopold, R.A., K.J. Hughes and J.D. DeVault. 1996. Using electroporation and a slot cuvette to deliver plasmid DNA to insect embryos. Gen. Anal. Biomol. Eng. 12: 197-200.

Lewis, W. J., P. B. Haney, J. R. Ruberson and S. Phatak. 1996. Continued studies of insect population dynamics in crimson clover and refugia/cotton systems, Part I: Sweep and whole plant sampling. Proc. Beltwide Cotton Conf. 2: 1108-1114.

Lewis, W. J., W. Sheehan and J. H. Tumlinson. 1994. Unraveling the story of how parasitoids fund their hosts. *In* Pest Management in the Subtropic: Biological Control - A Florida Perspective (Eds. David Rosen, Fred D. Bennett, and John L. Capinera). Intercept Ltd., Andover, Hamshire, UK, pp 671-680.

Lewis, W. J., J. C. van Lenteren, J. H. Tumlinson and S. Phatak. Sustainable insect pest managment: A total systems perspective. Approved by AO for Biological Control. Proc. Natl. Acad. Sci. In Press

Liang, C., J. L. Willers, S. Bridges and J. M. McKinion. 1996. *Cotton Talk*: A speech interface for cotton plant mapping, pp. 522-528. Proc. Beltwide Cotton Conf, National Cotton Council, Memphis, Tennessee.

Lingren, P. D., J. K. Westbrook, V. M. Bryant, Jr., J. R. Raulston, J. F. Esquivel and G. D. Jones. 1994. Origin of corn earworm (Lepidoptera: Noctuidae) migrants as determined by Citrus pollen markers and synoptic weather systems. Environ. Entomol. 23(2): 562-570.

Loughrin, J. H., A. Manukian, R. R. Heath, T. C. J. Turlings and J. H. Tumlinson. 1994. Diurnal cycle of emission of induced volatile terpenoids by herbivore-injured cotton plants. Proc. Natl. Acad. Sci. 91: 11836-11840.

Lopez, J. D., Jr., C. G. Clemens and R. W. Meola. 1997. Evaluation of some insecticides mixed with a feeding stimulant for adult bollworm, pp. 940-941. Proc. Beltwide Cotton Conference.

Lopez, J. D., Jr., D. L. Bull and P. D. Lingren. 1996. Feeding of adult *Helicoverpa zea* (Lepidoptera:Noctuidae) on dry sucrose. J. Econ. Entomol. 89: 119-123.

Lopez, J. D., Jr., W. L. Sterling, D. A. Dean and D. A. Nordlund. 1996. Chapter 3 - Biology and ecology of important predators and parasites attacking arthropod pests, pp. 88-142. *In* E. G. King, J. R. Phillips, and R. J. Coleman [eds.] Cotton Insects and Mites: Characterization and Management. Cotton Foundation Reference Book Series.

Lopez, J. D., Jr., K. R. Beerwinkle, J. L. Goodenough and J. A. Witz. 1995. Spatial and temporal patterns of catches in pheromone traps of *Helicoverpa zea* and *Heliothis virescens* in Central Texas. *In* J. R. Raulston, and J. E. Slosser [eds.], Noctuids: Recent Advances in Detection and Migration in the U.S. Southwest. Entomol. Suppl. No. 18: 5-24.

Lopez, J. D., Jr., P. D. Lingren and D. L. Bull. 1995. Proboscis extension response of adult *Helicoverpa zea* (Lepidoptera:Noctuidae) to dry sugar. J. Econ. Entomol. 88(5): 1271-1278.

Lopez, J. D., Jr., J. L. Goodenough and K. R. Beerwinkle. 1994. Comparison of two sex pheromone trap designs for monitoring corn earworm and tobacco budworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 87: 793-801.

Lynch, R. E., J. A. Wightman and G. V. Ranga Rao. 1997. Part III. Insects and Arthropods. *In:* Compendium of Peanut Diseases Second Edition (Kokalis-Burelle et al. Eds.). The American Phytopathological Society. 94 p.

Lynch, R. E. 1996. Peanut fungicides: Effect on survival and development of the corn earworm, fall armyworm, and velvetbean caterpillar. Peanut Science 23: 116-123.

Lynch, R. E. and T. P. Mack. 1995. Biological and Biotechnical Advances for Insect Management in Peanut--Biological Control and Biotechnology in Entomology. Chapter 4, pp. 95-159. *In* Advances in Peanut Science, Harold E. Pattee and H. Thomas Stalker (eds.). American Peanut Research and Education Society, Stillwater, OK. 614 pp.

Lynch, Robert E. and Glenn W. Burton. 1994. Relative abundance of insects on bermudagrasses and bahiagrasses. J. Entomol. Sci. 29: 120-129.

Lynch, Robert E. and Alvin M. Simmons. 1993. Distribution of immatures and monitoring of adult sweetpotato whitefly, *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae), in peanut, *Arachis hypogaea*. Environ. Entomol. 22(2): 375-380.

Mack, T. P., D. P. Davis and R. E. Lynch. 1993. Development of a system to time scouting for the lesser cornstalk borer (Lepidoptera: Pyralidae) attacking peanuts in the Southeastern United States. J. Econ. Entomol. 86(1): 164-173.

Mannion, C. M., J. E. Carpenter and H. R. Gross. 1995. Integration of inherited sterility and a parasitoid, *Archytas marmoratus* (Diptera: Tachinidae), for managing *Helicoverpa zea* (Lepidoptera: Noctuidae): Acceptability and suitability of hosts. Environ. Entomol. 24(6): 1679-1684.

Mannion, C. M., J. E. Carpenter and H. R. Gross. 1995. Integration of inherited sterility and a parasitoid, *Archytas marmoratus* (Diptera: Tachinidae), for managing *Helicoverpa zea* (Lepidoptera: Noctuidae): Acceptability and suitability of hosts. Environ. Entomol. 24(6): 1679-1684.

Mannion, C. M., J. E. Carpenter, B. R. Wiseman and H. R. Gross. 1994. Effect of host corn earworm (Lepidoptera: Noctuidae) reared on meridic diet containing silks from a resistant corn genotype on *Archytas marmoratus* (Diptera: Tachinidae) and *Ichneumon promissorius* (Hymenoptera: Ichneumonidae). Environ. Entomol. 23: 837-845.

Mannion, C. M., J. E. Carpenter, B. R. Wiseman and H. R. Gross. 1994. Host corn earworm (Lepidoptera: Noctuidae) reared on meridic diet containing silks from a resistant corn genotype on *Archytas marmoratus* (Diptera: Tachinidae) and *Ichneumon promissorius* (Hymenoptera: Ichneumonidae). Environ. Entomol. 23: 837-845.

Mannion, C. M., J. E. Carpenter and H. R. Gross. 1994. Potential of the combined use of inherited sterility and a parasitoid, *Archytas marmoratus* (Diptera: Tachinidae), for managing *Helicoverpa zea* (Lepidoptera: Noctuidae). Environ. Entomol. 23: 41-46.

Mannion, C. M., J. E. Carpenter, B. R. Wiseman and H. R. Gross. 1994. Host corn earworm (Lepidoptera: Noctuidae) reared on meridic diet containing silks from a resistant corn genotype on *Archytas marmoratus* (Diptera: Tachinidae) and *Ichneumon promissorius* (Hymenoptera: Ichneumonidae). Environ. Entomol. 23: 837-845.

Maramorosch, K. and A. H. McIntosh. 1994. [eds.] Arthropod Cell Culture Systems. CRC Press, Inc., Boca Raton, An Arbor, Boston, London.

Maramorosch, K. and A. H. McIntosh. 1994. [eds.] Insect Cell Biotechnology. CRC Press, Inc., Boca Raton, Ann Arbor, Boston, London.

Mardaus, M. C. and J. S. Buckner. 1997. Identification and characterization of novel short chain acid esters as surface lipid components of *Heliothis virescens* pupae. Effects of sorbic acid in the diet. Insect Biochem. Molec. Biol. (In Press).

Martin, S. H., G. W. Elzen, J. B. Graves, S. Micinski, B. R. Leonard and E. Burris. 1995. Toxicological responses of tobacco budworm (Lepidoptera: Noctuida) from Louisiana, Mississippi, and Texas to selected insecticides. J. Econ. Entomol. 88: 505-511.

Mardaus, M. C. 1994. The identification of novel cuticular pupal lipids of the tobacco budworm, *Heliothis virescens*. M.S. Thesis, North Dakota State University.

Matis, J. H., S. Yang, N. Castiaux, J. K. Westbrook, K. R. Beerwinkle and J. D. Lopez, Jr. 1995. Predicting the date of first catch of the corn earworm, *Helicoverpa zea*, in central U. S., pp. 58-72. *In* J. R. Schwenke [ed.], Proceedings, 1995 Kansas State Univ. Conf. on Appl. Stat. in Agric., 23-25 April 1995, Kansas State University, Manhattan.

McCall, P. J., T. C. J. Turlings, J. H. Loughrin, A. T. Proveaux, and J. H. Tumlinson. 1994. Herbivore-induced bolatile emissions from cotton (*Gossyplum hirsutum* L.) seedlings. J. Chem. Ecol. 20(12): 3039-3050.

McCall, P. J., T. C. J. Turlings, W. J. Lewis and J. H. Humlinson. 1993. Tole of plant volatiles in host location by the special parasitoid *Microplitis crocelpes* (Cresson) (Braconidae: Hymenoptera). J. Insect Behavior 6: 625-639.

McIntosh, A. H., J. J. Grasela and R. L. Matteri. 1996. Identification of insect cell lines by DNA amplification fingerprinting (DAF). Insect Molec. Biol. 5(3):187-195.

McIntosh, A. H., J. J. Grasela and C. L. Goodman. 1995. Replication of *Helicoverpa zea* nuclear polyhedrosis virus in homologous cell lines grown in serum-free media. J. Invertebr. Pathol. 66:121-124.

McIntosh, A. H. and J. J. Grasela. 1994. Specificity of baculoviruses, pp. 57-69. *In*: K. Maramorosch and A. H. McIntosh [eds]

McIntosh, A. H. and J. J. Grasela. 1994. Expression of beta-galactosidase and luciferase in insect cell lines infected with an AcMNPV recombinant. Virto Cell. Dev. Biol. 30A: 275-278.

McMillian, W. W., N. W. Widstrom and D. M. Wilson. 1993. Registration of GT-MAS:gk maize germplasm. Crop Sci. 33: 882.

Mitchell E.R., J.A. Leach, 1994. A Yellow Mutant *Heliothis virescens* (Lepidoptera Noctuidae). J. Entomol. Sci. 29(4): 509-512.

Narang, S. K., J. E. Carpenter, L. J. Heilmann, J. D. DeVault and J. D. Lopez. 1994. DNA fingerprinting of *Helicoverpa zea* populations: deciphering the source of migrants. p. 252-270. Proceedings 1993 ARS Heliothis Suppression Action Plan. ARS 1994-6.

Narang, S. K., J. E. Carpenter, L. J. Heilmann, J. D. DeVault and J. D. Lopez. 1994. DNA fingerprinting of *Helicoverpa zea* populations: deciphering the source of migrants. p. 252-270. Proceedings 1993 ARS Heliothis Suppression Action Plan. ARS 1994-6.

Nelson, D. R. and C. L. Fatland. 1997. Very Long-Chain Methyl-Branched Alcohols and Their Acetate Esters in the Internal Lipids of Lepidopteran Pupae: *Cochylis hospes, Diatraea grandiosella, Homoeosoma electellum, Heliothis virescens* and *Helicoverpa zea.* Comp. Biochem. Physiol. 116B: 243-256.

Nelson, D. R. and J. S. Buckner. 1995. The surface hydrocarbons of larval *Heliothis virescens* and *Helicoverpa zea.* Comp. Biochem. Physiol. 111B: 681-689.

Olson, R. L., T. L. Wagner, S. Yatham, M. R. Williams and J. L. Willers. 1992. Design and implementation of rbWHIMS-An expert system or cotton pest management, pp. 777-782. Proc. Beltwide Cotton Prod. Res. Conf., Nashville, TN.

Pair, S. D. and J. K. Westbrook. 1995. Agro-ecological and climatological factors potentially influencing fall armyworm populations and their movement in the southeastern United States. *In* J. R. Raulston, and J. E. Slosser [eds.], Noctuids: Recent Advances in Detection and Migration in the U.S. Southwest. Entomol. Suppl. No. 18: 101-118.

Pair, S. D., J. R. Raulston, A. N. Sparks, J. K. Westbrook, W. W. Wolf and J. L. Goodenough. 1995. A Prospectus: Impact of *Helicoverpa zea* (Boddie) production from corn in the lower Rio Grande Valley on regional cropping systems., *In* J. R. Raulston, and J. E. Slosser [eds.], Noctuids: Recent Advances in Detection and Migration in the U.S. Southwest. Entomol. Suppl. No. 18: 155-167.

Pair, S. D. 1994. Japanese honeysuckle (Caprifoliaceae): A newly discovered host of *Heliothis virescens* and *Heliothis zea* (Lepidoptera: Noctuidae). Environ. Entomol. 23: 906-911.

Pair, S. D. and R. J. Horvat. Volatiles of Japanese honeysuckle flowers as attractants for adult lepidopteran insects. U.S. Patent Appl. P.C. 0017.95/filed 11/09/95.

ParJ, P. W. and J. H. Tumlinson. 1997. Induced synthesis of plant volatiles. Nature 30-31.

ParJ, P. W. and J. H. Tumlinson. 1996. Plant volatile signals in response to herbivore feeding. Fla. Entomol. 79(2): 93-103.

Prokopy, R. J. and W. J. Lewis. 1993. Application of learning to pest management, pp. 308 342. *In* Insect Learning: Ecological and Evolutionary Perspectives (D. R. Papaj and A. Lewis, Eds.), Chapman and Hall, New York. 398 p. (Book Chapter)

Quhou, Chen, A. H. McIntosh and C. M. Ignoffo. 1984. Establishment of two new cell lines from the yellow-striped armyworm, *Spodoptera orinithogalle* (Lepodoptera: Noctuidae). J. Central China Teachers College 3:101-108.

Rafaeli, A., V. Soroker, J. Hirsch, B. Kamensky and A. K. Raina. 1993. Influence of photoperiod and age on the competence of pheromone glands and on the distribution of immunoreactive PBAN in *Helicoverpa* spp. *Arch. Insect Biochem. Physiol.* 22: 169-180.

Raina, A. K., D. M. Jackson and R. F. Severson. 1997. Increased pheromone production in wild tobacco budworm (Lepidoptera: Noctuidae) exposed to host-plants and host chemicals. *Environ. Entomol.* 26: 101-105.

Raina, A. K. 1996. Control of pheromone production in moths. In: Insect Pheromone Research: New Directions, Eds. R. T. Card and A. K. Minks, Chapman & Hall, New York, pp. 21-30.

Raina, A. K. and J. R. Adams. 1995. Gonad-specific virus of corn earwom. *Nature*. 374: 770.

Raina, A. K. 1995. Eco-physiology of sex pheromone production in some species of moths. In: Proc. *1st Intl. Conf. Insects: Chemical, Physiological and Environmental Aspects,* Ladek-Zdroj. D. Konopinska Ed. Univ. Wroclaw Press., pp. 86-91.

Raina, A. K. and A. Rafaeli. 1995. PBAN: What all we know. *In* Proc. Intl. Symp. Molecular Mechanisms of Insect Metamorphosis and Diapause, Eds. A. Suzuki, H. Kataoka and S. Matsumoto, Industrial Publishing & Consulting, Tokyo, pp. 151-160.

Raina, A. K., T. G. Kingan and J. M. Giebultowicz. 1994. Mating-induced loss of sex pheromone and sexual receptivity in insects with emphasis on *Helicoverpa zea* and *Lymantria dispar. Arch. Insect Biochem. Physiol.* 25: 317-327.

Raina, A. K., A. Rafaeli and T. G. Kingan. 1994. Pheromonotropic activity of orally administered PBAN and its analogues in *Helicoverpa zea. J. Insect Physiol.* 40: 393-397.

Raulston, J. R., J. K. Westbrook, J. Loera, S. D. Pair, P. D. Lingren and D. R. Rummel. 1994. Temporal occurrence of corn earworm, *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae) populations in the Lower Rio Grande Valley, Uvalde, and Lubbock, Texas. *In* J. R. Raulston, and J. E. Slosser [eds.], Noctuids: Recent Advances in Detection and Migration in the U.S. Southwest. Entomol. Suppl. No. 18: 81-100.

R`se, U. S. R., A. Manukian, R. R. Heath and J. H. Tumlinson. 1996. Volatile semiochemicals released from undamaged cotton leaves: a systemic response of living plants to caterpillar damage. Plant Physiology 111: 487-495.

R`se, U. S. R., H. T. Alborn, G. Macranczy, W. J. Lewis and J. H. Tumlinson. Host recognition by the specialist endoparasitoid *Microplitis croceipes* (Hymenoptera: Braconidae). J. Insect Behav. In Press.

Ruberson, J. R., W. J. Lewis, D. J. Waters, O. Stapel and P. B. Haney. 1995. Dynamics of insect populations in a reduced-tillage, crimson clover/cotton system Part I: Pests and beneficials on plants. Proc. Beltwide Cotton Conf. 2: 814-817.

Ruberson, J. R., G. A. Herzog and W. J. Lewis. 1993. Parasitism of the beet armyworm, *Spodoptera exigua*, in south Georgia cotton. Proc. Beltwide Cotton Conf. 2: 993-997.

Schlotzhauer, William S., Pair, S.D. and Horvat, R.J. 1996. Volatile constituents from the flowers of Japanese honeysuckle (*Lonicera japonica*). J. Agric. Food Chem. 44: 206-209.

Sequeira, R. A., J. L. Willers and R. L. Olson. 1996. Validation of a deterministic model-based decision support system. AI Apps. 10: 25-40.

Sequeira, R. A., R. L. Olson and J. L. Willers. 1996. An intelligent, interactive data input system for a cotton simulation model. AI Apps. 10: 41-56.

Sequeira, R. A., R. L. Olson, J. L. Willers and J. M. McKinion. 1994. Automating the parameterization of mathematical models using genetic algorithms. Comput. Electron. Agric. 11: 265-290.

Shahjahan, R.M. K.J. Hughes, R.A. Leopold and J.D. DeVault. 1995. Lower incubation temperature increases yield of genomic DNA isolated by the CTAB method. Biotechniques. 19: 333-334.

Shaver, T. N., P. D. Lingren and H. F. Marshall, Jr. 1997. Nighttime variation in volatile content of flowers of the night blooning plant *Gaura drummondii*. Journal of Chemical Ecology, in press.

Shaver, T. N. and J. D. Lopez, Jr. 1996. Ovipositional response of the tobacco budworm and bollworem to checkpea. Southwest Entomol. 21: 277-282.

Sheehan, W., F. L. Wàckers and W. J. Lewis. 1993. Discrimination of previously searched, host-free sites by *Microplitis croceipes* (Hymenoptera: Braconidae). J. Insect Behavior 6(3): 323-331.

Singsit, C., M. J. Adang, R. E. Lynch, W. F. Anderson, A. Wang, G. Cardineau and P. Ozias-Akins. 1996. Expression of a *Bacillus thuringiensis* CryIA8 gene in transgenic peanut plants and its efficacy against lesser cornstalk borer. Transgenic Research 5: 1-8.

Smith, M. T. and D. D. Hardee. 1996. Influence of fungicides on development of an entomopathogenic fungus (Zygomycetes: Neozygitaceae) in the cotton aphid (Homoptera: Aphididae). Environ. Entomol. 25: 677-687.

Smith, M. T. and D. D. Hardee. 1993. Seasonal relationship among cotton aphid (*Aphis gossypii* Glover), the entomopathogenic fungus, *Neozygites fresenii* (Nowakowski) Batko, and the parasite, *Lysiphlebus testaceipes* (Cresson). Proc. Beltwide Cotton Prod. Res. Confs., pp. 978-982.

Smith, M. T. and D. D. Hardee. 1993. Influence of fungicides applied at planting on seasonal development of the entomopathogenic fungus, *Neozygites fresenii* (Nowakowski) Batko, in the cotton aphid (*Aphis gossypii* Glover). Proc. Beltwide Cotton Prod. Res. Confs., pp. 744-746.

Snook, M. E., B. R. Wiseman, N. W. Widstrom and R. L. Wilson. 1997. Chemicals associated with maize resistance to corn earworm and fall armyworm. pp. 37-45. *In* J. A. Mihm (ed.), Insect Resistant Maize: Recent Advances and Utilization. Proc. of an International Symposium held at the International Maize and Wheat Improvement Center (CIMMYT), 27 November - 3 December 1994. Mexico, D.F.: CIMMYT. 302 p.

Snook, M. E., N. W. Widstrom, B. R. Wiseman, P. F. Byrne, J. S. Harwood and C. E. Costello. 1995. New C-4"-hydroxy derivatives of maysin and 3'-methoxymaysin isolated from corn silks (*Zea mays*). J. Agric. Food Chem. 43: 2740-2745.

Snook, M. E., N. W. Widstrom, B. R. Wiseman, P. F. Byrne, J. S. Harwood and C. E. Costello. 1995. New C-4"-hydroxy derivatives of maysin and 3'-methoxymaysin isolated from corn silks (*Zea mays*). J. of Agricultural and Food Chemistry 43(10): 2740-2745.

Snook, M. E., N. Widstrom, B. R. Wiseman, R. C. Gueldner, R. L. Wilson, D. S. Himmelsbach, J. S. Harwood and C. E. Costello. 1994. New flavonol-C-Glycosides from corn (*Zea mays*) for the control of the corn earworm(*Helicoverpa zea*). pp. 122-135. In P. A. Hedin (ed.). Bioregulators for Crop Protection and Pest Control. ACS Symposium Series #557. 221 p.

Snook, Maurice E., R. E. Lynch, A. K. Culbreath and C. E. Costello. 1994. 2,3-Di-(E)-caffeoyl-(2R,3R)-(+)-tartaric acid in terminals of peanut (*Arachis hypogaea* L.) varieties with different resistances to late leaf spot disease {*Cercosporidium personatum* (Berk. & M.A. Curtis) Deighton} and the insects tobacco thrips {*Frankliniella fusca* (Hinds)} and potato leafhopper {*Empoasca fabae* (Harris)}. J. Agric. Food Chem. 42:1572-1574.

Snook, Maurice E., N. W. Widstrom, B. R. Wiseman, R. C. Gueldner, R. L. Wilson, D. S. Himmelsbach, J. S. Harwood and C. E. Costello. 1994. New flavone C-glycosides from corn (*Zea mays* L.) for the control of the corn earworm (*Helicoverpa zea*). Chapter 10, pp. 122-135. *In*: Paul A. Hedin (ed.), ACS Symposium Series 557, Bioregulators for Crop Protection and Pest Control. 221 pp.

Snook, M. E., R. C. Gueldner, N. W. Widstrom, B. R. Wiseman, D. S. Himmelsbach, J. S. Harwood and C. E. Costello. 1993. Levels of maysin and maysin analogues in silks of maize germplasm. J. Agric. Food & Chem. 41: 1481-1485.

Snook, Maurice E., R. C. Gueldner, N. W. Widstrom, B. R. Wiseman, D. S. Himmelsbach, J. S. Harwood and C. E. Costello. 1993. Levels of maysin and maysin analogues in silks of maize germplasm. Journal of Agricultural and Food Chemistry 41: 1481-1485.

Soares, G. G., Jr., W. J. Lewis, J. M. Strong-Gunderson, D. J. Waters and J. J. Hamm. 1994. Integrating the use of MVP Bioinsecticide, a unique B.T.-based product, with natural enemies of noctuid pests: A novel concept in cotton IPM. Proc. Second Canberra *Bacillus thuringiensis* Meeting.

Stapel, J. O., J. R. Ruberson, H. R. Gross and W. J. Lewis. 1997. Progeny Allocation of parasitoid *Lepesia archippivora* (Diptera: Tachinidae) in larvae of *Spodoptera exigua* (Lepidoptera: Noctuidae) in larvae of *Spodoptera exigua* (Lepidoptera: Noctuidae). Environ. Entomol. 26: 265-271.

Stapel, J. O., A. M. Cortesero, C. M. DeMoraes, J. H. Tumlinson and W. J. Lewis. Importance of extrafloral necaries on food and host searching behavior of *Microplitis croceipes* (Hymenoptera: Braconidae) in cotton. J. Chem. Ecol. In Press.

Stevens, G. L., J. L. Willers, R. A. Sequeira and P. D. Gerard. 1996. Analysis of deterministic simulation model performance using non-replicated factorial two-level experiments. Agric. Systems 52: 293-315.

Stowe, M. K., T. C. J. Turlings, J. H. Loughrin, W. J. Lewis and J. H. Tumlinson. 1995. The chemistry of eavesdropping, alarm, and deceit. Proc. Natl. Aca. Sci. Colloquium, "Chemical Ecology: The Chemistry of Biotic Interaction 19: 23-28.

Streett, D. A., M. R. Bell and D. D. Hardee. 1997. Update on the areawide budworm/ bollworm management program with virus: Is it a cost effective insurance program? Proc. Beltwide Cotton Prod. Res. Confs. (In Press).

Stuart, M. K. and M. H. Greenstone. 1997. Immunological detection of hymenopteran parasitism in *Helicoverpa zea* and *Heliothis virescens*. Biol. Control. 8: 197-202.

Subhash, C. G., T. D. Leathers, G. N. El-Sayed and C. M. Ignoffo. 1994. Relationships among enzyme activities and virulence parameters in *Beauveria bassiana* infections of *Galleria mellonella* and *Trichoplusia ni*. J. Invertebr. Pathol. 64:13-17.

Szocs, G., A. K. Raina, M. Toth and B. A. Leonhardt. 1993. Sex pheromone components of *Heliothis maritima*: Chemical identification, flight tunnel and field tests. *Ent. Exp. Appl.* 66: 247-253.

Takasu, K. and W. J. Lewis. 1996. The role of learning in adult food location by the parval parasitoid *Microplitis croceipes*. J. Insect Behav. 9: 265-281.

Takasu, K. and W. J. Lewis. 1995. Importance of adult food sources to host searching of the larval parasitoid, *Microplitis croceipes*. Biological Control 5: 25-30.

Takasu, K. and W. J. Lewis. 1993. Host-and-food-foraging of the parasitoid *Microplitis croceipes*: Learning and physiological state effects. Biological Control 3: 70-74.

Tillman, P. G., J. L. Roberson and D. D. Hardee. 1997. Disposable cardboard box for rearing/ release of *Microplitis croceipes*. Submitted to Southwestern Entomol.

Tumlinson, J. H., W. J. Lewis and L. E. M. Vet. 1993. How beneficial parasitic wasps find plant feeding caterpillars. Sci. Amer. 268: 100-106.

Tumlinson, J. H., T. C. J. Turlings and W. J. Lewis. 1993. Semoichemically mediated foraging behavior in beneficial parasitic insects. Arch. Insect Biochem. And Physiol. 22: 385-391.

Turlings, T. C. J., J. H. Loughrin, P. J. McCall, U. S. R. Rose, W. J. Lewis and J. H. Tumlinson. 1995. How caterpillar-damaged plants protect themselves by attracting parasitic wasps. Proc. Natl. Acad. Sci. Colloquium, Self-defense by Plants: Induction and signaling pathways. 92: 1469-1479

Turlings, T. C. J., F. Wàckers, L. E. M. Vet, W. J. Lewis and J. H. Tumlinson. 1993. Learning of host location cues by insect parasitoids, pp. 51-78. *In* Insect Learning: Ecological and Evolutionary Prespectives (D. R. Papaj and A. Lewis, Eds.). Chapman and Hall, New York. 398 p (Book Chapter).

Turlings, T. C. J., P. J. McCall, H. T. Alborn and J. H. Tumlinson. 1993. An elicitor in caterpillar oral secretions that induces corn seedlings to emit volatiles attractive to parasitic wasps. J. Chem. Ecol. 19(3): 411-425.

Vail, P. V., D. F. Hoffmann, J. S. Tebbets. 1996. Effects of fluorescent brightner of the activity of *Anagrapha falcifera* (Lepidoptera: Noctuidae) nuclear polyhedrosis virus to four noctuid pests. Biol. Control. 7:121-125.

Vail, P. V., T. J. Henneberry, D. F. Hoffmann, M. R. Bell, L. J. Jeck and J. S. Tebbets. 1993. The influence of a bait and fluorescent brightener on activity of the celery looper polyhedrosis virus for lepidopterous cotton pests. Cotton Insect Res. And Control Conf., 1993 Beltwide Cotton Conf., pp. 1014-1016.

Vakharia, V. N., A. K. Raina, T. G. Kingan and T. G. Kempe. 1995. Synthetic pheromone biosynthesis activating neuropeptide gene expressed in a baculovirus expression system. *Insect Biochem. Molec. Biol.* 35: 583-589.

Vet, L. E. M., W. J. Lewis and R. T. Carde. 1995. Parasitoid foraging and learning in chemical ecology of insects, II (R. T. Carde and W. Bell, ed.). Chapman and Hall, New York, pp. 65-101.

Wàckers, F. L. and W. J. Lewis. 1994. Olfactory and visual learning and their interactive influence on host site location by the parasitoid, *Microplitis croceipes*. Biological Control 4: 105-112.

Wagner, T. L., R. L. Olson, J. L. Willers and M. R. Williams. 1996. Modeling and computerized decision aids. *In* E. G. King, and J. R. Phillips [eds.], Cotton Insects and Mites: Characterization and Management, Cotton Foundation Reference Book Series No. 3, Memphis, TN.

Wagner, T. L., D. C. Akins, T. L. Wagner and M. R. Williams. 1995. User's guide for rbWHIMS: An expert system for managing cotton arthropod pests in the Midsouth. Miss. Agric. For. Exp. Stn. Tech. Bull. 207.

Wagner, T. L., M. R. Williams, J. L. Willers, D. C. Akins, R. L. Olson and J. M. McKinion. 1995. Knowledge base of rbWHIMS: An expert system for managing cotton arthropod pests in the midsouth. Miss. Agric. For. Exp. Stn. Tech. Bull. No. 205. July 1995.

Wagner, T. L. and J. L. Willers. 1992. The role and relationship of the database with insect population model. *In* J. L. Goodenough, and J. M. McKinion [eds.], Basics of Insect Models. ASAE Monograph No. 10.

Wagner, T. L., R. L. Olson and J. L. Willers. 1991. Methods for modeling arthropod development. J. Agric. Entomol. 8: 251-270.

Wang, Y-S., T. G. Kempe, A. K. Raina and P. H. Mazzocchi. 1994. Conformation of a biologically active C-terminal hexapeptide analog of the pheromone biosynthesis activating neuropeptide by NMR spectroscopy. Int. J. Peptide Protein Res. 43: 277-283.

Ward, K. E., J. L. Hayes, R. C. Navasero and D. D. Hardee. 1993. Genetic variability in oviposition preference among and within populations of the cotton bollworm, *Helicoverpa zea* (Lepidoptera: Noctuidae). Ann. Entomol. Soc. Amer. 86: 103-110.

Weathersbee, A. A., III, D. D. Hardee and W. R. Meredith. 1995. Yield impact of cotton aphid on 12 cotton cultivars differing in leaf trichome density. Proc. Beltwide Cotton Prod. Res. Conf., pp. 893-895.

Weathersbee, A. A., III, D. D. Hardee and W. R. Meredith, Jr. 1995. Differences in yield response to cotton aphids (Homoptera: Aphididae) between smooth-leaf and hairy-leaf isogenic cotton lines. J. Econ. Entomol. 88: 749-754.

Weathersbee, A. A., III and D. D. Hardee. 1994. Abundance of cotton aphids (Homoptera: Aphididae) and associated biological control agents on six cotton cultivars. J. Econ. Entomol. 87: 258-265.

Weathersbee, A. A., III and D. D. Hardee. 1994. Yield comparison between smooth and hairy isolines of cotton subjected to different levels of aphid infestation. Proc. Beltwide Cotton Prod. Res. Conf., pp. 1003-1006.

Weathersbee, A. A., III, D. D. Hardee and W. R. Meredith. 1994. Effects of cotton genotype on seasonal abundance of cotton aphid (Homoptera: Aphididae). J. Agric. Entomol. 11: 29-37.

Weathersbee, A. A., III and D. D. Hardee. 1993. Indices of relative abundance for the cotton aphid, *Aphis gossypii* Glover, and associated parasitoids, pathogens, and predators on six cotton cultivars. Proc. Beltwide Cotton Prod. Res. Confs., pp. 733-737.

Weirich, G. F., J. P. Kochansky, E. P. Masler, W. R. Lusby, M. F. Feldlaufer, A. K. Raina and J. A. Svoboda. 1995. Degradation of pheromone biosynthesis-activating neuropeptide (PBAN) by hemolymph enzymes of the tobacco hornworm, *Manduca sexta*, and the corn earworm, *Helicoverpa zea*. *Experientia* 51: 961-966.

Westbrook, J. K. and P. D. Lingren. Meteorology, plant attractants, and potential for development of adult control technology for noctuid pests. Southwest. Entomol. Suppl. (in press).

Westbrook, J. K., W. W. Wolf, P. D. Lingren, J. R. Raulston, J. D. Lopez, Jr., J. H. Matis, R. S. Eyster, J. F. Esquivel and P. G. Schleider. 1997. Early-season migratory flights of corn earworm (Lepidoptera:Noctuidae). Environ. Entomol. 26: 12-20.

Westbrook, J. K., W. W. Wolf, J. R. Coppedge, J. R. Raulston and J. D. Lopez, Jr. 1997. Effects of weather on areawide pest management, pp. 65-73. *In* C. W. Richardson, G. L. Johnson, V. A. Ferreira, and P. C. Doraiswamy, [eds.], Proceedings, ARS Workshop on Climate and Weather Research, Denver, CO, 17 July 1995, Washington, DC: US Department of Agriculture, Agricultural Research Service.

Westbrook, J. K., P. D. Lingren and R.J.V. Joyce. 1996. Insect activity and distribution, pp. 436-437. *In* R. T. Watson, M. C. Zinyowera, and R. H. Moss [eds.], Climate Change 1995-Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, England.

Westbrook, J. K., J. R. Raulston, W. W. Wolf, S. D. Pair, R. S. Eyster and P. D. Lingren. 1995. Field observations and simulations of atmospheric transport of noctuids from northeastern Mexico and the south-central U. S. *In* J. R. Raulston, and J. E. Slosser [eds.], Noctuids: Recent Advances in Detection and Migration in the U.S. Southwest. Entomol. Suppl. 18: 25-44.

Westbrook, J. K., R. S. Eyster, W. W. Wolf, P. D. Lingren and J. R. Raulston. 1995. Migration pathways of corn earworm indicated by tetroon trajectories. Agric. Forest. Meteorol. 73: 67-87.

Westbrook, J. K., W. W. Wolf, S. D. Pair, J. R. Raulston, R. Eyster and P. D. Lingren. 1995. Field observations and simulations of atmospheric transport of noctuids from northeastern Mexico and South-Central U.S. *In* J. R. Raulston, and J. E. Slosser [eds.], Noctuids: Recent Advances in Detection and Migration in the U.S. Southwest. Entomol. Suppl. No. 18: 25-44.

Westbrook, J. K., P. D. Lingren, W. W. Wolf and J. R. Raulston. 1994. New Concepts in Migration Research. *In* J. R. Raulston, J. R. Coppedge, R. M. Faust, and P. D. Lingren [eds.], *Heliothis/Helicoverpa*: 1993 Supplement to the Five-Year National Research Action Plan for Development of Suppression Technologies, First Annual Review Held in Junction, Texas, 8-11 November 1993. U. S. Department of Agriculture, Agricultural Research Service, Washington, D. C.

Westbrook, J. K., W. W. Wolf, P. D. Lingren and J. R. Raulston. 1994. Tracking tetroons to evaluate tobacco budworm and bollworm migration, pp. 791-793. *In* 1994 Proceedings, Beltwide Cotton Conferences, 5 January 1994. San Diego, CA.

Westbrook, J. K., W. W. Wolf, P. D. Lingren and J. R. Raulston. 1994. Flight speed and heading of migrating corn earworm moths relative to drifting tetroons. Proceedings of the Amer. Meteorol. Soc. 11th Conf. on Biometeorology and Aerobiology, 423-426. San Diego, CA 7 March 1994. Boston, MA: Amer. Meteorol. Soc.

Widstrom, N. W., R. A. Flath and P. J. Loesch, Jr. 1997. Chemical and genetic attributes of a maize-silk olfactory trait. J. Agric. Food Chem. 45: 217-220.

Widstrom, N. W. 1996. The aflatoxin problem with corn grain. *In:* Advances in Agronomy. Academic Press, Inc. Chapter 6. (Book Chapter).

Widstrom, N. W., M. J. Forster, W. K. Martin and D. M. Wilson. 1996. Agronomic performance in the southeastern United States of maize hybrids containing tropical germplasm. Maydica 41: 59-63.

Widstrom, N. W. and B. R. Wiseman. 1996. Insect screening results: Evaluation of corn hybrids for resistance to insects. pp. 25-28. *In:* Anton E. Coy, J. LaDon Day, and Paul L. Raymer (eds.), 1996 Corn Performance Tests. Ga. Agric. Exp. Stns., Coll. of Agric. and Environ. Sciences, Univ. of Ga. Res. Rept. 642.

Widstrom, N. W., M. E. Snook, D. M. Wilson, T. E. Cleveland and W. W. McMillian. 1995. Silk maysin content and resistance of commercial corn (maize) hybrids to kernel contamination by aflatoxin. J. Sci. Food Agric. 67:317-321.

Widstrom, N. W. and B. R. Wiseman. 1995. Insect screening results: Evaluation of corn hybrids for resistance to insects. pp. 28-31. *In:* Anton E. Coy, J. LaDon Day, Paul L. Raymer (eds.), 1995 Corn Performance Tests. Ga. Agric. Expt. Stns., College of Agric. and Environ. Sciences, Univ. of Georgia Research Report Number 637.

Widstrom, N. W. and C. C. Dowler. 1995. Sensitivity of selected field corn inbreds (*Zea mays*) to nicosulfuron. Weed Technology, Vol. 9: 779-782.

Widstrom, N. W. and M. E. Snook. 1994. Inheritance of maysin content in silks of maize inbreds resistant to the corn earworm. Plant Breeding 112: 120-126.

Widstrom, N. W. and B. R. Wiseman. 1994. Insect screening results: Evaluation of corn hybrids for resistance to insects. pp. 27-31. In: J. LaDon Day, Anton E. Coy, Robert B. Bennett, and Paul L. Raymer (eds.), 1994 Corn Performance Tests. Ga. Agric. Expt. Stns., Coll. of Agric. and Environ. Sciences, Univ. of Ga. Res. Rept. 631.

Widstrom, N. W., W. W. McMillian, D. M. Wilson, J. L. Richard, N. Zummo and R. W. Beaver. 1994. Preharvest aflatoxin contamination of maize inoculated with *Aspergillus flavus* and *Fusarium moniliforme*. Mycopathologia 128: 119-123.

Widstrom, N. W., K. Bondari and W. W. McMillian. 1993. Heterosis among insect-resistant maize populations. Crop Sci. 33: 989-994.

Widstrom, N. W. and B. R. Wiseman. 1993. Insect screening results: Evaluation of corn hybrids for resistance to insects. pp. 30-34. *In:* J. LaDon Day, Robert B. Bennett, and Paul L. Raymer (eds.), 1993 Corn Performance Tests. Ga. Agric. Exp. Stns., Coll. of Agric. and Environ. Sciences, Univ. of Ga. Res. Rept. 623.

Widstrom, N. W., W. P. Williams, B. R. Wiseman and F. M. Davis. 1993. Registration of GT-FAWCC(C5) Maize Germplasm. Crop Science 33: 1422.

Widstrom, N. W., D. M. Wilson, J. L. Richard and W. W. McMillian. 1993. Resistance in maize to preharvest contamination by aflatoxin. Trends in Agric. Sci. (Plant Pathol.) 1: 49-54.

Willers, J. L., S. Bridges, J. McKinion, X. Ma and C. Liang. 1996. Designing speech interface applications for acquisition of agricultural information, pp. 131-144. Proc. Applied Stat. Agric., Kansas State Univ., Manhattan.

Willers, J. L. and B. T. Vinyard. 1995. A classification of unreplicated factorial experiments for use with the analysis of deterministic simulation models, pp. 124-137. Proc. Applied Stat. Agric., Kansas State Univ., Manhattan.

Willers, J. L., T. L. Wagner, R. A. Sequeria, G. W. Theseira and D. L. Boykin. 1995. Analysis of deterministic simulation models using methods applicable to two-way treatment structures without replication. Agron. J. 87: 478-492.

Willers, J. L., R. A. Sequeira and S. B. Turner. 1994. The integration of insect simulation models and plant models: Some considerations, pp. 592-593. Proc. Beltwide Cotton Prod. Res. Conf., San Diego, CA.

Willers, J. L., S. R. Yatham, M. R. Williams and D. C. Akins. 1992. Utilization of the line-intercept method to estimate the coverage, density, and average length of row skips in cotton and other row crops, pp. 48-59. Proc. Applied Stat. Agric., Kansas State Univ., Manhattan.

Willers, J. L., D. L. Boykin, J. M. Hardin, T. L. Wagner, R. L. Olson and M. R. Williams. 1991. A simulation study on the relationship between the abundance and spatial distribution of insects and selected sampling scheme, pp. 33-45. Proc. Applied Stat. Agric., Kansas State Univ., Manhattan.

Willers, J. L., R. L. Olson, M. R. Williams and T. L. Wagner. 1990. Developing a Bayesian approach for estimating the proportion of cotton plants at risk to insect attack, pp. 246-247. Proc. Beltwide Cotton Prod. Res. Conf., Las Vegas, NV.

Williams, M. R., T. L. Wagner, J. L. Willers and R. L. Olson. 1995. Revised protocol for scouting arthropod pests of cotton in the Midsouth. Miss. Agric. For. Exp. Stn. Tech. Bull. No. 206. July 1995.

Williams, M. R., T. L. Wagner, J. L. Willers and R. L. Olson. 1992. A scouting protocol for arthropod pests of cotton, pp. 787-789. Proc. Beltwide Cotton Prod. Res. Conf., Nashville, TN.

Williams, M. R., T. L. Wagner, J. L. Willers and R. L. Olson. 1991. Scouting protocol for arthropod pests of cotton in the Midsouth. Agric. For. Exp. Stn. Bull. No. 977.

Wilson, R. L., B. R. Wiseman and M. E. Snook. 1995. Evaluation of pure red pericarp and eight selected maize accessions for resistance to corn earworm (Lepidoptera: Noctuidae) silk feeding. J. Econ. Entomol. 88: 755-758.

Wiseman, B. R., M. E. Snook, J. E. Carpenter and K. E. Espelie. 1998. Allelochemicals in maize resistant to *Spodoptera frugiperda* and *Helicoverpa zea*. Book Chapter. Allelochemicals. (At Publisher, Accepted).

Wiseman, B. R. 1998. Successes in plant resistance. ESA Symposium. ESA Thomas Say Misc. Pub. (Accepted).

Wiseman, B. R. and K. Bondari. 1997. Genetics of plant resistance to corn earworm. pp. 35-45. ed. K. Bondari. *In:* New Developments in Entomology. Research Signpost. Trivandrum, India.

Wiseman, B. R. 1997. Mechanisms of maize resistance to corn earworm and fall armyworm. pp. 46-54. *In* J. A. Mihm (ed.), Insect Resistant Maize: Recent Advances and Utilization. Proc. of an International Symposium held at the International Maize and Wheat Improvement Center (CIMMYT), 27 November - 3 December 1994. Mexico, D.F.: CIMMYT. 302 p.

Wiseman, B. R. 1997. Factors affecting a laboratory bioassay for antibiosis: Influence of maize silks on the corn earworm and fall armyworm larvae. pp. 211-216. *In* J. A. Mihm (ed.), Insect Resistant Maize: Recent Advances and Utilization. Proc. of an International Symposium held at the International Maize and Wheat Improvement Center (CIMMYT), 27 November - 3 December 1994. Mexico, D.F.: CIMMYT. 302 p.

Wiseman, B. R. 1997. Mechanisms of plant resistance against arthropod pests. Chap. 9. J. R. Ruberson. (ed.) Marcel Dekker: Handbook of Pest Management. CRC (Book Chapter) (At Publisher, Accepted).

Wiseman, B. R. and M. E. Snook. 1996. Flavone content of silks from commercial hybrids and growth responses of corn earworm (Lepidoptera: Noctuidae), larvae fed silk-diets. J. Agric. Entomol. 13: 239-249.

Wiseman, B. R., M. E. Snook and N. W. Widstrom. 1996. Feeding responses of corn earworm (Lepidoptera: Noctuidae) on corn silks of varying flavone content. J. Econ. Entomol. 89: 1040-1044.

Wiseman, B. R. and M. E. Snook. 1996. Maize plant resistance to corn earworm larvae. Arthropod Management Tests: 1996. 21: 420-421.

Wiseman, B. R., F. M. Davis, W. P. Williams and N. W. Widstrom. 1996. Resistance of a maize population, FAWCC(C5), to fall armyworm larvae (Lepidoptera: Noctuidae). Florida Entomol 79(3): 329-336.

Wiseman, B. R. and J. E. Carpenter. 1995. Growth inhibition of corn earworm (Lepidoptera: Noctuidae) larvae reared on resistant corn silk diets. J. Econ. Entomol. 88: 1037-1043.

Wiseman, B. R. and M. E. Snook. 1995. Effect of corn silk age on flavone content and development of corn earworm (Lepidoptera: Noctuidae) larvae. J. Econ. Entomol. 88: 1795-1800.

Wiseman, B. R. and K. Bondari. 1995. Inheritance of resistance in maize silks to the corn earworm. Entomol. exp. Appl. 77: 315-321.

Wiseman, B. R. 1994. Plant resistance to insects in integrated pest management. Plant Disease 78: 927-932.

Wiseman, B. R. and D. J. Isenhour. 1994. Mechanisms of resistance in maize to *Helicoverpa zea* and *Spodoptera frugiperda.* Proc. 10th South Africa Maize Breeding Symposium. 10: 51-55.

Wiseman, B. R. and D. J. Isenhour. 1994. Resistance of sweet corn to corn earworm. J. Agric. Entomol. 11: 157-163.

Wiseman, B. R. and J. J. Hamm. 1993. Nuclear polyhedrosis virus and resistant corn silks enhance mortality of corn earworm (Lepidoptera: Noctuidae). Biol. Control. 3: 337-342.

Wiseman, B. R. and D. J. Isenhour. 1993. Interaction of diet ingredients with levels of silk of a corn genotype resistant to the corn earworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 86: 1291-1296.

Wiseman, B. R., M. E. Snook and D. J. Isenhour. 1993. Maysin content and growth of corn earworm larvae (Lepidoptera: Noctuidae) on silks from first and second ears of corn. J. Econ. Entomol. 86: 939-944.

Wright, M. K., T. A. Coudron and S. L. Brandt. 1996. The physiological characteristics of the venom of the eulophid parasitoid *Euplectrus comstockii*: a chronicle of venom proteins, venom activity and storage protein titer within the hemolymph of *Trickoplusia ni*. Proc. XX Intl Congr. Entomol. 05-015, p 157.

Wolf, W. W., J. K. Westbrook, J. R. Raulston, S. D. Pair and P. D. Lingren. 1995. Radar observations of orientation of noctuids migrating from corn fields in the Lower Rio Grande Valley. Southwest. Entomol. Suppl. 18: 45-61.

Wolf, W. W., J. K. Westbrook, S. D. Pair, J. R. Raulston and P. D. Lingren. 1995. Observations of migratory flight orientation of noctuids arising from a corn growing region in the Lower Grande and its effects on downwind dispersal. *In* J. R. Raulston, and J. E. Slosser [eds.], Noctuids: Recent Advances in Detection and Migration in the U.S. Southwest. Entomol. Suppl. No. 18: 45-63.

Wolf, W. W., J. K. Westbrook, J. R. Raulston, S. D. Pair and P. D. Lingren. 1994. Radar detection of ascent of *Helicoverpa zea* (Lepidoptera:Noctuidae) moths from corn in the Lower Rio Grande Valley of Texas, pp. 1065-1074. *In* Proceedings of the 13th Intl. Congr. of Biometeorology, 12 September 1993, Calgary Alberta, Canada.

Wolf, W. W., J. K. Westbrook, J. R. Raulston, S. D. Pair and P. D. Lingren. 1994. Radar detection of ascent of *Helicoverpa zea* adults from maize in the Lower Rio Grande Valley, pp. 1065-1074. *In:* Proc. 13th Int. Congr. Aerobiol., 12-18 September 1993, Calgary, Canada.

Wrona, A., F. Carter, T. Dennehy, J. Diehl, P. Ellsworth, K. Hake, D. Hardee and 8 other authors. 1996. Cotton and resistant insects. Cotton Physiology Today, Vol. 7, No. 4, 4 pp. National Cotton Council, Memphis, TN.

Yang, G., B. R. Wiseman and K. E. Espelie. 1994. Effect of cuticular lipids from silks of selected corn genotypes on the development of the corn earworm. J. Entomol. Sci. 29: 239-246.

Appendix B. Meeting Agenda

Monday, October 6, 1997 Arrive

6:00 p.m. - Reception at Holiday Inn, College Station

Tuesday, October 7, 1997

FAPRL large conference room - Research and Status Overviews

Time	Speaker	Topic
8:00	J. R. Coppedge (LD) (Presiding)	Kick-off
8:05	C. A. Onstad (AD)	Welcome
8:15	R. M. Faust (NPL)	Objectives & Charge
8:30	Frank Carter(NCC)	Results of Cotton Industry Focus Groups and Future Expectations of the Cotton Industry on H/H Research
8:50	Mike Caprio (MSU)	*Bt* Cotton, Current Reality - Future Expectation
9:10	Patricia Pietrantonio (TAMU)	Resistance Management (Including *Bt* Cotton)
9:30	Paula Davis (Monsanto)	Transgenic Corn – Current Status and Future Perspectives
9:50	Sen Seong Ng (Abbott)	Current Status of Lepton Test Kits
10:10	Break	
10:30	Roger Leonard (LSU)	New Insecticides for H/H
10:50	Jack Batcheler (NCSU)	Ecology of H/H in the Carolinas
11:40	Lunch (catered)	Brown Bag Presentations
12:00	Ray Frisbie (TAMU) (Introduction by J. Coppedge)	Entomology Research, Teaching, and Extension in the Future - A Texas Perspective
12:30	Nick Toscano (UCR)	Entomology Research, Teaching, and Extension - A California Perspective

Tuesday, October 7. 1997

Indepth Research Presentations

Juan Lopez - Presiding

1:00	J. K. Westbrook	Movement and Migration of H/H
	J. R. Raulston	
	W. W. Wolf	
	P. D. Lingren	
1:30	D. D. Hardee	Areawide Management of H/H with Pathogens and Sterile Insects
	J. E. Carpenter	
2:00	Pat Morrison	Transgenic crops and IPM of the future
	T. Fuchs	
2:30	J. D. Lopez	Adult management of H/H with Attracticides
	T. N. Shaver	
	K. R. Beerwinkle	
3:00	G. W. Elzen	The Use of Selective Chemicals in the Management of H/H
3:30	W. J. Lewis	Ecologically Based Management of H/H in Post Boll Weevil Eradication
	J. Ruberson	Zones
4:00	P. G. Tillman	Biological control
	P. D. Greany	
	A. C. Cohen	
	A. K. Raina	
4:30		Adjourn
4:45		Meeting of Coordinating Committee - Holiday Inn Hospitality Room
6:00	Happy Hour	Wellborn Community Center
6:30	Barbecue	Wellborn Community Center

Person whose name is underlined is presenter and senior author.

Guest speaker - Larry Chandler (ARS, Brookings, SD) "The Joys of Managing a National Areawide Management Program"

7:30 - Initial rounds of horseshoes and washer pitching tournament.

Wednesday, October 8, 1997

8:00	J. Coppedge R. Faust	Technology Transfer and a H/H Research Plan for the Future
8:15	G. Foster	Virtual Laboratories

D. D. Hardee - Presiding

8:45	Group	Selection of Approach to New H/H National Plan Future Research Focus Areas - Discussion
10:00	Break	
10:30	Group	Selection of Thrust areas and Package Coordinators or Lead Scientist
12:00	Lunch (catered)	

Brown bag speaker. Ron Nachman "Insect Neurohormones and Their Potential for Use in Future H/H Management Programs" (Introduction by Juan Lopez)

Wednesday, October 8, 1997

James Coppedge - Presiding

Virtual CRIS's or approach (TBD)

1:15		Group Discussion of Research Package Area, Virtual CRIS's or Approach (TBD). Develop Lead Array or Objectives of CRIS. Initial Plan for the Future.
2:30	Break	
3:00		All Meet to Share Lead Arrays (Annual Milestones) or CRIS Titles and Objectives and Plan for the Future.
5:00	Adjourn	
6:00	Happy Hour	Wellborn Community Center
6:30	Fish Fry	Wellborn Community Center

Guest speaker - Bill Lingren - "The Use of Pheromones and Insect Traps in IPM Systems - A Worldwide Perspective"

7:30 - Championship rounds for horseshoes and washer pitching.
Trophy presentations

Appendix C. List of Registered Participants.

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